EXPLORING THE FOUNDATIONS OF CREATING, IMPLEMENTING, EVALUATING, AND REVISING SCIENCE, TECHNOLOGY, ENGINEERING, THE ARTS, AND MATHEMATICS (STEAM) CURRICULA IN THE CLASSROOM

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ABSTRACT

EXPLORING THE FOUNDATIONS OF CREATING, IMPLEMENTING, EVALUATING, AND REVISING SCIENCE, TECHNOLOGY, ENGINEERING, THE ARTS, AND MATHEMATICS (STEAM) CURRICULA IN THE CLASSROOM

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The value of conducting research around STEAM education (the amalgamation of the arts with science, technology, engineering, and mathematics) rests in better understanding current practices and the challenges teachers face when creating, implementing, evaluating, and revising a STEAM curriculum. This ethnographic case study examines how teachers, across different disciplinary content areas, make, utilize, implement, and evaluate STEAM curricula for students to become critical thinkers and create authentic work products. The data consisted of semi-structured interviews, two focus groups, and several observations of four teachers in their planning and implementing STEAM curricula. In the first phase of the study, the researcher mostly observed the process of the participants. At the end of this phase all the participants came together in a focus group to discuss and share their process. In the second phase, the researcher

examined how the participants would modify their processes based on their discussions with their colleagues. In addition, the researcher helped guide the teachers in applying these modifications to the STEAM process. The result of these sessions showed how the changes in teachers’ processes in creating, implementing, evaluating, and revising STEAM curricula created more opportunities for students to be critical and creative scholars. The findings from this study may help to inform researchers and educators on best practices to devise, execute, and evaluate STEAM lessons that have the potential to significantly impact students in their academic studies, careers, and futures.

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ACKNOWLEDGEMENTS

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C.C.Y.

Chapter I

INTRODUCTION

Our world reflects how arts are integrated with Science, Technology, Engineering, and Mathematics (STEM). Without the arts, John James Audubon never would have created a catalog of birds and their natural environments for researchers to study, and medical students would not have had the priceless illustrations of Frank Netter to rely on for learning human anatomy. Without the visual and musical arts, Disney Hall would not have existed to promote the sound of the Los Angeles Philharmonic Orchestra nor be a model for great architecture. Without the union of STEM and the arts, our world would lack the discoveries and inventions that have pushed us into the modern world.

As defined by The National Art Education Associate (NAEA), STEAM is the acronym given to “the infusion of art and design principles, concepts, and techniques into STEM instruction and learning” (National Art Education Associate, 2014, as cited in Liao, 2016, p. 45). STEAM is an integrated learning approach that merges the arts with STEM subjects for the purpose of improving student engagement, creativity, innovation, problem solving skills, and other cognitive benefits (Liao, 2016; NAEA, 2014; Sousa & Pilecki, 2013) and to improve employability skills (e.g., teamwork, communication, adaptability) necessary for career and economic advancement (Colucci-Gray et al., 2017).

STEAM creates a multidisciplinary space that cannot be defined in reference to any traditional sense of discrete disciplines. For instance, such a space is opened up when students do not separately categorize what they are learning as science, technology, engineering, mathematics, or art. Instead, students view their work as created through engaging with all these subjects and integrating concepts and skills from each of them in their work to in order to apply and draw from an integrated knowledge base that allows them to analyze and innovate solutions to problems in multiple settings (Liao, 2016; Quigley et al., 2017).

The Researcher

My whole life has centered around music and science: experiencing it as a life-long learner, educator, mentor, and more. I recognize the incredible lifelong impact the integration of the arts with science, technology, engineering, and mathematics, known as STEAM, can have on learning. Having grown up with a professional musician (my mother is a Juilliard-trained concert pianist), I have been fortunate to have received and been exposed to some of the finest musical training. As a young child, my mother shared with me what it took to be a musician: discipline, practice, and perfection, encompassing a plethora of various techniques and styles. My first music lessons began at age 4 when I started seriously studying the piano. By the time I was 9, I had debuted in concert halls in Hawaii, the Metropolitan Washington DC area, and at Temple Square in Salt Lake City, Utah. In college, I was fortunate enough to also be a soloist in performing some of the greatest choral works such as Orff's Carmina Burana, Mozart's Requiem, Handel's Alexander's Feast, and post-graduation I soloed at the Kennedy Center in Washington D.C.

Growing up, I also discovered a love for science. My father, both a medical doctor and researcher, also exposed and influenced my interests in the field. He would bring me to the museum each week and would always assist me in designing experiments for numerous at home "research studies" and for science fairs throughout primary and secondary school. During high school and college, I continued to spend my summers doing research but on a larger scale for the National Institutes of Health (NIH), where I was able to experience firsthand what some of the finest scientists in the world were working on. As I pursued both art and science, I realized the intersection that these seemingly different fields shared and how each one could not coexist without the other.

The intersection of science and music is what led me to be the best musician and the best scientist I could be. I realized that with music, I needed to understand the anatomy of my voice in order to incorporate healthy singing technique. In addition, being able to analyze and consider the engineering of the structures I was singing, this knowledge greatly assisted in helping me to not over sing and fatigue my voice. Music, in turn, helped me build my stamina and creativity in the lab. Like music, research also requires discipline, practice, creativity, and perfection in order to make discoveries. Also, like music, one must be creative as there is not always a road map to tell you exactly what to do. Being able to improvise is important to both fields as it could be the save to a live concert performance or the road to new discoveries in the lab.

Currently, I teach 6th grade Science and 9th grade Living Environment in addition to being the middle school choir director at a select public school in New York City. My experience with STEAM has allowed me to be a more impactful teacher so that my students can be better learners. Since the inception of my teaching career, I have increased the integration of the arts into my classroom. Within my lessons, I teach students that the arts give us the ability to communicate scientific ideas and help us to determine what to investigate, while science can help artists achieve their purpose. This has not only increased the number of students growing to enjoy and understand both subjects more, but it has also equipped them with the tools to see the connections between different parts of their education and how to make them more pertinent to their lives and future.

As a science and music educator with experience in both fields, I have seen the impact STEAM has on student learning. In my life, I struggled in school. In high school I was given a late diagnosis of dyslexia which made learning incredibly challenging. Growing up, however, I was also provided with extensive musical training, and the skills I garnered from this allowed me to find creative ways to overcome these challenges. In my teaching career, I saw students in similar situations, and I reflected and utilized my experience to assist them. Therefore, since the inception of my teaching career, I have increased the integration of the arts into my science classroom as I teach students that the arts give us the ability to communicate scientific ideas and help us to determine what to investigate, while science can help artists achieve their purpose. This has not only increased the number of students who enjoy and understand both subjects more but has equipped them with the tools to see the connections between different parts of their education and how to make multiple content areas more pertinent to their lives and their futures.

Background

Education is constantly influenced by changing societal contexts around how best to prepare students to be competitors and leaders of the future. One of the more recent movements has been the incorporation of the arts into the Science, Technology, Engineering, and Mathematics (STEM) curricula in order to better prepare students for the demands of the present and future workplace. This movement is grounded in research demonstrating that the value of the arts in the process of producing scientific knowledge is essential and should be a critical component of school curricula (Land, 2013; Madden et al., 2013).

On the face of it, Science, Technology, Engineering, Arts, and Mathematics (STEAM) education seems to be a further extension of STEM education. STEM started the movement of integrating curricula in order to foster skills that are representative of the real world, in contrast to traditional curricula which tend to be delivered in discrete courses that are not always be relevant to students' lives and do not always concentrate on genuine problems and issues

(Czerniak, 2007). Researchers considered traditional in silo pedagogy “artificial partitions with historical roots of limited contemporary significance” (p. 396). As Mason (1996) argues, traditional discipline-bound, fact-laden science courses are too narrow in scope to teach students how to learn in today’s world, where science, technology, and societal issues are all interrelated.

Since the promotion of curricular integration, educators have seen many positive effects on science instruction and curricula. The move towards an interdisciplinary approach has helped to equip students with skills to be better communicators, collaborators, problem solvers, and has further improved science teaching methods. Researchers of curricula have found that students form deeper understandings by seeing the “big” picture, make connections between the curricula and themselves, build connections among central concepts, and become interested and motivated in school when curricular integration is employed (Berlin, 1994; George 1996; Mason, 1996).

Building from a STEM curriculum, where the focus was only on science, technology, engineering, and mathematics, a STEAM curriculum fosters critical thinking skills by introducing innovation and divergent thinking in order to seek multiple solutions to problems (Hunter-Doniger & Sydow, 2016; Land, 2013; Madden et al., 2013). With a shift towards STEAM, researchers and educators have not only seen these skills continue to grow (Watson & Watson, 2013) but have also seen fruitful new learning approaches take hold. The Framework for 21st Century Learning (2017) states that “an arts-integrated approach[s] to STEAM education affirms the process of creative production, utilizes the creative process to acquire knowledge, and teach 21st century skills, such as communication and collaboration” (p. 21).

An ongoing issue with STEM fields is a lack of diversity. The initial design of STEM advocated for the movement to recruit individuals who usually did not go into STEM fields, typically students of color and women. Many of those students lose interest in science and mathematics when taught in a traditional, discrete manner, which has resulted in many students making an early exit from the STEM fields (Blackley & Howell, 2015; Mensah & Jackson, 2018; Sanders, 2009). More recent research has found that by broadening student understanding of STEM disciplines through exposure to socially and culturally relevant STEM contexts and by increasing the pathways for students to enter the STEM fields, STEM has been able to retain students (Wang et al., 2011). Although these results are encouraging, there is hope for a larger increase of those entering the field, especially those from underrepresented groups. There is hope that students previously not interested and/or excluded in STEM and the arts that students will be motivated to learn in the STEAM classrooms and ultimately pursue careers in these fields (Hunter-Doniger & Sydow, 2016; Taylor, 2016).

Traditional paradigms for science education focus on the learning of science with little regard for the sociocultural context or the cultural composition of learners (Atwater, 1996). In contrast, artistic learning strategies can help students overcome existing limitations in traditional subjects (Madden et al., 2013). The arts provide the missing component necessary to pique student interest by making it more relatable and relevant to their own lives and circumstances (Hunter-Doniger & Sydow, 2016).

The STEAM platform grew from a lack of creativity and innovation in recent college graduates in the U.S. (Land, 2013). Research done by Merryman and Bronson (2010) found that IQ scores are rising while creativity scores are falling. This is problematic because employers are looking for creative problem solvers for a twenty-first century workforce (Hunter-Doniger & Sydow, 2016). Science is inherently creative; however, it is not being taught that way (hence the need for STEAM), which has caused a lack of creativity in graduates. Therefore, the amalgamation of the arts and STEM, or STEAM, allows the scientists to develop creativity, problem solving, critical thinking, communication, self-direction, initiative, and collaboration – all of the skills students need to successfully survive as an adult in an increasingly complex and technologically driven world (Sousa & Pilecki, 2013). Albert Einstein stated (1929), "I am enough of an artist to draw freely upon my imagination. After a certain high level of technical skill is achieved, science and art tend to coalesce in esthetics, plasticity, and form. The greatest scientists are artists as well" (October 26, Personal Interview).

Problem Statement

STEAM holds much promise in increasing student success as compared to curricula that are discipline-specific. Various factors, such as the lack of strategy, lack of professional development, lack of structured time to work together, and in-class challenges, have been strenuous for educators in creating, implementing, and delivering STEAM curricula. There is little conceptualization of STEAM beyond "adding the arts" (Kim & Park, 2012a; Miller & Knezke, 2013), which makes it difficult for teachers to implement this pedagogical practice. STEAM has been conceptualized through a narrow-disciplinary approach that does not provide educators with guidance on how STEAM is different from STEM (Quigley et al., 2017). There is ample acknowledgement of the benefits of a STEAM curriculum; however, there are few resources and little literature around how STEAM can and should be executed in schools.

Purpose of the Study

The purpose of this ethnographic case study is to understand the experiences of four middle school teachers implementing STEAM curricula in their classrooms. The strategies and practices that they employ were examined to understand the process of creating, implementing, evaluating, and revising STEAM curricula in the classroom.

Research Questions

To shed light on the purpose of this study, I address the following research questions:

1. How do middle school STEM and arts teachers create STEAM, an interdisciplinary curriculum?
    a. How is STEAM defined by middle school teachers?
    b. Why do teachers choose to create STEAM curriculum/lessons?
    c. How do teachers bring STEAM into their content area courses?
2. How do STEAM classrooms function?
    a. How do teachers engage student learning in a STEAM environment?
    b. How does STEAM improve student learning outcomes compared to traditional classrooms (i.e.,, classrooms that do not teach interdisciplinary curriculum)?
    c. How do STEAM lessons shape students' understanding of STEAM fields and their ability to transfer their learning across other learning environments or classes?
3. How do teachers reflect and act on their implementation and assessment of STEAM teaching in order improve STEAM curriculum/lessons?
    a. How do experienced teachers reflect on their work to improve STEAM curricula?
    b. How do teachers use student work to guide their curriculum revision process?

Organization of the Dissertation

The organization of this dissertation is presented in the following way: Chapter I of this dissertation provides an introduction and rationale for this study. Chapter II provides a literature review, which discusses the influences on STEAM, the challenges educators face creating and implementing STEAM, and the elements for curriculum design. Chapter III describes the methods used to conduct this research, which includes an ethnographic case study and traditional qualitative methods. Chapter IV is a summary of my findings and provides a profile for how each of my participants creates, implements, evaluates, and revises STEAM curricula. Chapter V provides a discussion of the findings and the themes among how my participants create, implement, evaluate, and revise STEAM curricula. Lastly, Chapter VI provides implications, limitations, and future research for this study.

Chapter II

LITERATURE REVIEW

The literature review covers much relevant research and scholarship related to STEAM education and teacher professional development. This synthesis is organized to cover theoretical frameworks that have influenced the development of STEAM, challenges educators face creating and implementing STEAM, key elements for curriculum design, and practitioner development. Based upon this literature review, I developed a conceptual framework that explains the cycle of the impact STEAM has on educators, students, and ultimately society. This can be found at the end of this chapter.

Influences on the Development of STEAM

STEM Education

Over time, various influences have affected the development of STEAM education and curricula. Prior to STEAM was the push for STEM education. In 2008, President Obama, who was a major advocate for STEM education, stated, "Today, more than ever before, science holds the key to our survival as a planet and our security and prosperity as a nation. It's time once again to put science at the top of our agenda and work to restore America's place as a world leader in science and technology" (Obama, 2008, as cited in Land, 2013, p. 548). With his support and the work of other public officials, organizations developed and funded various STEM educational projects. In addition to the presidential push, the United States has created the STEM Coalition and the Next Generation Science Standards (NGSS), which stress science and engineering knowledge and practices (Jho et al., 2016). In spite of these efforts, unfortunately, the United States is still behind other countries in the rankings for science, mathematics, and literacy and has not made much progress since the Obama era (PISA, 2015).

STEM is Interdisciplinary

STEM reignited movement towards integrated curriculum in order to foster authentic skills useful in real-world settings. Czerniak (2007) wrote that “in real life, people do not separate their daily tasks into separate subjects; therefore, it seems only rational that subject areas should not be separated in our schools” (p. 537). As, STEM education has grown to encourage integrated curricula, researchers have noted many positive effects (Blackley & Howell, 2015; Sanders, 2009). Mark Sanders (2009) defined this integration as teaching and learning between two or more STEM subjects or between a STEM subject and a non-STEM subject. This pedagogical approach combined technical design with scientific inquiry to create “purposeful design and inquiry” (p. 21). The rationale for this was that in a world outside of schools, “design and scientific inquiry are routinely employed concurrently in the engineering of solutions to real-world problems” (Sanders, 2009).

As researchers and educators continue to refine and revise this movement, they continuously define how to implement the partnership among subjects. Currently, STEM is perceived as an interdisciplinary approach where there is a problem or issue that centers the content and skills in multiple disciplines. By practicing and continuing to develop STEM in this manner, students are equipped to critically think, problem solve, and make connections with learning experiences that relate to their experiences. Using this method, students are taught to see the “big” picture, make curriculum relevant to themselves, build connections among central concepts, and become interested and motivated in school (Berlin, 1994; George, 1996; Mason, 1996).

Science education, in particular, has shifted towards an interdisciplinary approach with The Next Generation Science Standards (NGSS) (Sanders, 2009). The NGSS is rooted in this approach and has even delineated dimensions of learning on how science can be integrated with other subjects. NGSS defines specifically how to execute these skills through its three dimensional framework: scientific and engineering practices, cross cutting concepts, and disciplinary core ideas. NGSS moves teaching away from the focus on learning isolated facts about subjects to a focus on specific disciplinary core ideas and crosscutting concepts that can be used to explain phenomena and solve problems by engaging in science and engineering practices (Krajcik et al., 2014). These three dimensions work in symphony to help students build an integrated understanding of a rich network of connected ideas that can be applied to solving long term issues (Krajcik et al., 2014; NGSS, 2013; Pruitt, 2015). STEAM takes similar approaches to both NGSS and STEM but also adds the "arts" to the conversation in order to cultivate creativity (Liao, 2016). By increasing creativity, participants' creating, inventing, innovating, and engineering capacities increase even further (Watson & Watson, 2013). The common goal of preparing students to be critical thinkers, problem solvers, and critical analyzers is shared by NGSS, STEM and STEAM.

Fall of Creativity

Another factor influencing the STEAM educational initiative has been the fall of creativity. In a controversial article, "The Creative Crisis" by Merryman and Bronson (2010), researchers found that IQ scores were rising while creativity scores were falling. Further, there has been a dramatic decrease in innovative American ideas, and we are now finding the U.S. falling from ranking 3rd to 8th in innovation (White, 2010). Historically the U.S. was considered the leading country in innovation. Deloitte's (2015) report on Information Technology (IT) workers of the future argues that creativity is a key priority and that STEM educators need to embrace the arts in order to foster students' creative design and performance, using various media (Taylor, 2016). As a result, in 2007, the concept of STEAM was introduced to help counterbalance the increased focus on STEM subjects and the decline in arts education in the U.S. over the past decade (Martin et al., 2013; Spohn, 2008).

Economy

Our rapidly evolving economy demands divergent thinkers whose cognition is both flexible and original. The "Not Coming to America" study done by the Partnership for a New American Economy found that jobs in STEM fields are increasing three times faster than positions in the rest of the economy, but there is a gap of qualified American citizens to fill them (McDougall, 2012). Only 4.4% of US born undergraduates are enrolled in STEM programs as compared to other countries (McDougall, 2012). Business and industry leaders are calling for graduates with liquid skills that enable them to adapt to a fluid working landscape throughout their lives. Educators are asked to prepare for jobs that currently do not exist, but that will be essential to the nation's economic well-being (Taylor, 2016).

Biological Changes

Neurologists have also come to find that when individuals are taught a single concept, the brain creates neural pathways connecting the concept to his or her experience (Land, 2013). The more access points or neural pathways established, the greater the chances of retention and recall. By moving from STEM to STEAM and integrating the arts into core content areas, students are enabled to explore a single concept from different vantage points, incorporating all the different modalities of learning previously mentioned, while utilizing leading to the formation of more neural pathways (Land, 2013).

Challenges Educators Face Creating STEAM

Challenges Defining STEAM

While STEAM education holds much promise, various factors have challenged educators in creating and implementing STEAM curricula. Through the literature, creativity is heavily mentioned; however, there are few articles that expand upon the ways in which creativity is developed, practiced, or fostered through STEAM education (LaJevic, 2013; Liao, 2016; Perignat & Buonincontro, 2019; Quigley & Herro, 2016). Defining the arts has been a point of contention as STEAM develops. Some scholars, National Art Education Association NAEA (2016); NCCAS (2013); Costantino's (2018) as cited in Perignat and Buonincontro (2019),

> consider the "arts" to represent "Art Education" specific to visual art (paintings, drawing, photography, sculpture, media arts, and design), while others refer to "Arts Education" (plural "arts") referring to a variety of arts including visual, performing (dance, music, theater) digital media, aesthetics, and crafts, and still others expand the definition to include the liberal arts and humanities disciplines. (pp. 31-32)

The National Art Education Association (NAEA) published a position statement on STEAM, defining it as "the infusion of art and design principles, concepts, and techniques into STEM instruction and learning" (National Art Education Association, 2014 as cited in Liao, 2016). Research by Silverstein and Layne (2010) define arts integration as an approach to teaching in which students construct and demonstrate understanding through an art form. On the other hand, some use the term "Arts" as synonymous for project-based learning, technology based-learning, or design-based learning (Perignat & Buonincontro, 2019).

In some cases, more established teaching communities develop a mission statement around their intended goals. The challenge, however, is that those involved do not always interpret it the same way and therefore, the creation of materials is not always on the same page (Huffman, 2003). In other situations, schools that do not have as developed procedures resort to using the vision of the district, which sometimes bounce from one innovation or program to another. This results in fragmentation of efforts and lack of commitment by teachers and administrators (Huffman, 2003). As a result, with little conceptual or empirical work to guide educators, it can be challenging for STEAM development, implementation, and evaluation of STEAM-based teaching practices (Kim & Park, 2012; Yackman, 2008).

As STEAM is a developing field, how it is defined continues to evolve. The parameters that delineate what qualifies as STEAM and what does not have yet to be set. What further contributes to this challenge is that each area does not seem to have a working definition of STEAM. The current literature requires that one search for how each STEM subject individually works with the arts rather than how STEAM is defined by each STEM subject. This section examines those relationships within each specific field in hopes of identifying the overlaps and assist in setting the boundaries of STEAM.

In the literature, the arts are valued among all the STEM subjects. There is evidence to suggest that all STEM subjects believe that the arts allow students to be more successful in problem solving as the arts assist in making complex concepts more tangible by relating them to student cultures (Asiabanpower et al., 2010; Izadi, 2017; Schovers et al., 2018). All subjects have also observed that when the artistic process is fostered students tend to be more creative in their ability to generate more creative solutions (Asiabanpour et al., 2010; Dietiker, 2015; Hadzigeorgiou et al., 2012).

Across certain STEAM subjects, joint arguments are also made in support of integrating the arts into STEM. Mathematics and science agree that the arts assist in the development of students’ visual imagination which can be useful in both these subjects for further processing of content (Izadi, 2017; Schoevers et al., 2018). Science and engineering also had several overlaps in how they define the benefits of the arts added to their subjects as well. Both found that those who thrived in science and engineering had good communication skills that were fostered through including the arts in their subject areas (Asiabanpour et al., 2010; Izaid, 2017).

Lack of Strategy for Creating STEAM Curriculum

Since STEAM is a rather new educational movement, STEAM goals and strategies for achieving those goals have not fully been defined. This leads to difficulty in creating STEAM lessons. In a survey conducted by Perignat and Buonincontro (2018), faculty and students interested in the potential for art and design to be integrated into their STEM courses for the effective enhancement of creativity lacked specific strategies for doing so. As a result, practitioners are challenged to design or implement effective methods for STEAM (Henrkisen et al., 2015; Kim & Park, 2012; Liao, 2016; Quigley & Herro, 2016). In another study by Henrkisen et al., (2015), some teachers used existing STEM models and attempted to “add on” experiences with arts or humanities (Henrkisen et al., 2015; Kim & Park, 2012; Quigley & Herro, 2016). People like the idea of STEAM but are easily put off when faced with creating and implementing it because of the lack of specificity (Bequette, 2015).

Lack of Training

When tasked with creating STEAM lessons, educators struggled due to a lack of preparation across different subject areas. Like students schooled in a traditional sense, educators have also gone through the system of being taught subjects in silos. Non-arts educators have struggled with strategies for reintroducing the arts for the purpose of enhancing student creativity and innovative thinking in STEM curricula (Rabkin & Hedberg, 2011). This was further emphasized by Rabkin and Hedberg (2011), who studied non-arts educators in the United States and struggled to find effective strategies for arts integration into their curriculum. As a result, arts integration beyond design can often be difficult for content area teachers to achieve (Quigley & Herro, 2016). Sometimes STEM teachers misunderstand the arts and refer to the use of the arts in the classroom to enhance teaching and learning. For example, in a study by Bequette and Bequette (2012) researchers reported that some students were asked to color a bridge they had built in a STEM lesson without talking about the artistic choices they had made (or the other artistic engineering choices that went into constructing the bridge). Unfortunately when this occurs, the arts are often watered down in classroom practices (LaJevic, 2013). If you can take the arts out and it does not change the lesson, then STEAM teachers are not truly doing STEAM. The arts should not be acting subservient to other subjects, but instead should both be linked intentionally and be critical to the lesson.

Working Together

Current literature has shown that there have been difficulties in the collaboration of teachers in the various STEAM fields. Successful STEAM curriculum development typically requires the collaboration of teachers from other disciplines (Jho et al., 2016; Lee et al., 2013; Noh & Paik, 2014); however, there can be resentment towards certain subjects. There is a common misconception that creativity is connected solely to the arts; therefore, students must participate in the arts in order to develop creativity (Perignat & Buonincontro, 2019). Sochacka et al. (2016) explain that individuals in STEM sometimes

> felt unsatisfied by what we considered to be a narrow and simplistic view of the arts as a panacea for increasing the creative abilities of STEM students, not to mention… the

> implicit assumption that engineering and other STEM fields are somehow inherently lacking in creative ways of thinking. (Sochacka et al., 2016, p. 33)

In contrast, the arts are sometimes perceived as less important, an idea that has unfortunately been supported by certain education movements such as the STEM movement, when arts programs were greatly decreased in public schools to give more support for only STEM subjects (Association of American Educators [AAE], 2012), or namely literacy and mathematics which is given priority over science in elementary classrooms (Berg & Mensah, 2014; Mensah, 2010). Researchers and authors in both the arts and in the sciences argue that creativity is inherent in all disciplines, not just the arts as it is often perceived (Perignat & Katz-Buonincontro, 2018).

Educators have also reported difficulty in communicating with teachers of other subjects due to the different cultures and natures of the disciplines (Lee et al., 2013; Noh & Paik, 2014). In line with these findings, Van Alsvoort (2004) addressed the issue of "the irrelevance of chemistry in secondary education due to the division between science and society" (Van Alsvoort, 2004 as cited in Jho et al., 2016). These findings suggest that teaching is contextualized under the influence of various social factors such as the negotiation of goal of teaching norms of classroom, and educational context.

Lastly, research suggests that time is a limiting factor that hinders teachers' abilities to create STEAM curricula. Researchers have found that educators sometimes struggle to coordinate their demanding schedules in addition to having curricular restrictions due to school curricular policy and state and national standards (Herro & Quigley, 2016; Jho et al., 2016). Hunter-Doniger and Sydow (2016) also reported that participants of their study were provided with little time to work with both arts and academic subjects. Not being able to collaborate with experts in these subjects poses challenges when trying to create an interdisciplinary curriculum.

Challenges Educators Face Implementing STEAM

Teacher Confidence in Carrying Out STEAM Lessons

The research on the implementation of STEAM can be impactful; however, both educators and researchers have reported several challenges in implementing STEAM lessons in the classroom. In a study by DeJarnette (2018), it was found that elementary teachers were reluctant to implement STEAM curriculum into their classrooms, even after receiving a professional development workshop and all the resources needed to implement the lessons. The teachers reported that they enjoyed the learning and were confident their students would as well; however, when it came to delivery, they refused to execute them on their own (DeJarnette, 2018). The teachers in the study needed and advocated for additional professional development to fully implement and feel comfortable with STEAM lessons within their classrooms on their own (DeJarnette, 2018).

Lack of Resources and Technology

Teacher confidence was also challenged when it came to trying out new technologies. Quigley and Herro (2016) found that teachers struggled with remaining flexible and rethinking approaches when technology was introduced into lessons. In that same study, it was also reported that resource availability was also a barrier to implementing STEAM lessons. One teacher reported, “I only wish I had Chrome Books or newer technology” (p. 420). Another teacher reported that he did not integrate technology citing that access was a primary issue.

With low teacher confidence, lack of resources and technology being concerns, these issues can compound and create significant barriers to STEAM instruction. For example, in a study examining teacher practice and student engagement during the transition from STEM to STEAM, researchers Hunter-Doniger and Sydow (2016) also came across several challenges during the implementation phase of their STEAM lessons. They reported that a lack of time available to work with both the arts and academic subjects during lessons impeded how much content students were able to gain. They also mentioned that funding for projects and resources became a challenge when trying to implement lessons. In addition, technology availability during classes was limited and was expensive both to purchase and then maintain (Hunter-Doniger & Sydow, 2016). Several of these same issues came up and were echoed in a study conducted by Kang (2019).

Teacher Collaboration

Similar to the creation of STEAM, teacher collaboration when implementing lessons has been challenging for teachers. In attempts to implement STEAM lessons, some teachers have noted that there is an inability to conceptualize STEAM without support from other disciplines (Quigley & Herro, 2016). Research has also shown that the inability to engage colleagues from other disciplines in common projects makes implementation of STEAM lessons difficult (Quigley & Herro, 2016).

Student Ability and Attitudes in the Classroom

In Quigley and Herro's (2016) study, researchers found that students had difficulty connecting topics to local issues. This task turned out to be less intuitive than teachers originally conceived. Supporting multiple students' abilities was difficult while simultaneously providing them with independence (a characteristic that separates STEAM education from other types of learning). Student groupings and attitudes for collaborative work also posed challenging in the implementation phase. Teachers made statements such as, "The groups are not working well together" and "I have to move groups a lot. It seems that they don't know how to work together, or one person is doing all the work?" (p. 422).

Elements for Curriculum Design and Implementation

Although approaches to teaching STEAM are rather new, certain practices have held promise in being effective in motivating students. For many students, the inclusion of the arts often makes the other disciplines more relatable to a broader audience, which in turn helps students see connections to the real world and what they are learning in the classroom (Quigley et al., 2017). STEAM-based curricula produce a higher percentage and wider diversity of students interested in pursuing careers to support the fields of mathematics and science (Masata, 2014). As can be evidenced from various studies, students previously not interested in STEM subjects have increased their engagement when some aspect of the arts was added.

Current STEAM Approaches

One model created by Quigley et al. (2017), known as STEAM Classroom Assessment of Learning Experiences (SCALE), suggests that well-executed STEAM learning experiences draw on a set of desirable knowledge (Instructional Content) and pedagogy (Learning Context). In order to achieve powerful learning outcomes, the types of content selected, the ways in which content areas are put together, and the problem solving skills that are taught must be included in the Instructional Content domain. As for the Learning Context, learning environments that support student learning in the classrooms not only include the instructional practices teachers use but also their assessment practices as well as the ways they support equitable participation across students with diverse abilities and interests (Jamil et al., 2017).

In another study by Miller and Knezek (2013), the researchers examined the effectiveness of a STEAM professional development (PD) called "STEAM approaches using WeDo and NXT robotic systems." In the PD, teachers collaborated with other teachers, problem solved, researched, investigated, created, and published content (Miller & Knezek, 2013). At the PD, local community members were also brought in to collaborate with the teachers. Post PD, teachers then implemented these same lessons in their classrooms. The study found that when the liberal arts were integrated with science, student achievement in mathematics and science increased. In addition, the incorporation of twenty first century skills such as collaboration and creativity, along with problem solving through the use of technology, achievement increased in specific subjects as well. The Illinois Mathematics and Science Academy (IMSA) found similar results using a problem-based learning scenario that considered local context.

In an engineering study by Connor, Karmokar, and Whittington (2015) researchers found connections between STEAM and problem solving. They examined how the inclusion of the liberal arts into STEM, for the purposes of removing boundaries between traditional subjects between science, technology, engineering, and arts, helped to dismantle "disciplinary egocentrism," the inability to think outside of one's perspective of the knowledge, skills, and methods gained through being trained within a specific discipline (Richter, Paretti, & McNair, 2009), what researchers believed caused students to be unable to engage in multiple disciplines to solve problems. They also discussed ways to create projects that are flexible enough to accommodate different student interests, which is student directed rather than teacher directed.

Another possibility is integrating the way pre-service teachers learn across the teacher education curriculum. While STEAM education is still developing and laying its foundation, there is a scarcity of larger scale teacher preparation programs. However, STEM education, which has taken a similar interdisciplinary and transdisciplinary approach to teaching and student learning has had success with developing integrated professional programs and can serve as a model for future STEAM teacher development. For example, Virginia Tech created the *Integrative STEM Education Program* offering certificates and advanced degrees specifically for

STEM education. In this program, pre-service and in-service teachers seeking these certifications/degrees, “build on existing knowledge and experience to expand their understanding of STEM education through the exploration of integrative strategies for teaching STEM concepts, often through design –based and transdisciplinary challenges” (Virginia Tech [VT], 2019). Pre- and in-service teachers learn how “framing problems in terms of design-based challenge provides springboard for investigations. Also, placing the concepts in relevant contexts helps students see immediate value of what they are learning while they are practicing their twenty first century skills of teamwork, communication, and problem solving” (Virginia Tech, 2019).

Maker Spaces

Students also very much appreciate hands-on, imaginative approaches to science education, using many of the methods used in the creative arts. Bequette (2015) found that these methods have been shown to attract and retain young people in the fields of science, technology, engineering, and mathematics. One aspect of curriculum design that has held much promise has been the approach of maker spaces. Maker spaces provide a setting for students to work with tools, machines to do work, project design, and crafting materials, measurement technology, and work benches (Banks-Hunt et al., 2016). Unlike traditional laboratory classrooms, maker spaces help students recognize engineering in the world around them, and opportunities to literally make the world a better place (Anderson, 2015). The focus on the process that leads to the creation of a final product in current STEAM literature has been successful at achieving science literacy and arts-based skills. In art the process of making is “arguably more important than the final product itself in the domain of art” (Perignat & Katz-Buonincontro, 2018). The process to create requires exploration, creative thinking, designing, technique, creative expression, evaluation, and redesign—skills required to carry out art projects and laboratory work. In a study by Guyotte et al. (2014), teams of students designed and created ways to reduce solid waste in order to improve water sustainability. Their focus on local and global sustainability through the design process showed the value in exploring the science and mathematics that underpin different artistic techniques. Therefore, when developing curricula, teachers and researchers should include activities and lessons that emphasize this process.

Problem Based Learning

Research has shown that problem-based learning has held much promise in helping students achieve scientific and artistic literacy (Cook & Bush, 2018). Students need to be able to adapt and function in different domains; therefore, in order to adequately prepare students, learning should take place in authentic and real-world environments. These environments are not usually the outcome of a single specific, isolated domain (Dolittle & Hicks, 2003). The construction of knowledge is enhanced when the experience is authentic so that the individual may construct mental structures that are viable in meaningful situations (Dolittle & Hicks, 2003; Madden et al., 2013). Further supporting this argument, Hunter-Doniger and Sydow (2016) found that through a creative and interdisciplinary approach to STEM standards, projects can be designed to have useful application and address real-life situations and issues.

Herro and Quigley (2016), after evaluating a STEAM professional development, foundthat effective STEAM teaching positions teachers to create problem solving scenarios that foreground problems for students to solve, using creative and collaborative skills that encompass various disciplines. This is markedly different from traditional teaching where students begin with the content and then solve explicit problems (Quigley et al., 2017). By taking a STEAM approach, students can address problem solving through a real-world application in which there is no definite answer and multiple disciplines are acknowledged in that the scenario incorporates the use of several disciplines such as engineering practices. For example, in once classroom, a teacher introduced the problem of cooking food using a renewable energy source and then asked students to design a solar oven. The teacher giving the lesson was then able to assess her students' knowledge on energy, renewable, and non-renewable resources, light reflection, properties of bacteria, and engineering design (Quigley & Herro, 2016).

In another a study conducted by DeJarnett (2018), students were given a hypothetical scenario where a gingerbread man (based off the children's book *The Gingerbread Man*) had to design a boat for him to travel across a river. While the subject of the scenario is fictitious, students had to use engineering design to "imagine, plan, create, and improve their designs" (Jackson et al., 2011) in order to create an efficient boat around certain material and cost restrictions. This lesson modeled issues that designers face in the real world around regulations and production of products.

In a review by Perignat and Buonincontro (2018), the researchers also found that STEAM programs tend to overlook the critique of art education. The critique process and conveying meaning are characteristics of art education which have shown to improve students' verbal and non-verbal communication skills, openness to various perceptions, understanding of sociocultural dynamics, and understanding through reflection of their own experiences and emotions. The critiquing process also enhances students' communication skills, listening, interpretation, reasoning, and learning through feedback (Costantino, 2018). These skills are also key to obtaining knowledge when investigating problems in STEM classrooms.

Equity among STEAM Fields

Through the development of STEAM, researchers and teachers are continuously making efforts to provide and address equity in order to reach a broader student body of K-8 learners. One of the major goals of STEAM is to involve the arts in order to increase the participation of students who are traditionally absent from STEM (Perignat & Katz-Buonincontro, 2018). By employing artistic learning strategies, students can overcome existing limitations in traditional subjects (i.e.,, focus on tests and memorization) by exposing students to a different way of seeing the world (Watson & Watson, 2013). For example, Bush, Cox, and Cook (2016) described how a mathematics focused STEAM project was able to highlight the benefit of arts integration into STEM which engaged more types of learners. Sharapan (2012) found that when integrating STEAM, the arts brought in by lessons was able to assist children in expressing STEM concepts.

The arts have also been known to provide the missing component necessary to pique student interest and creativity in STEM subjects (Hunter-Doniger & Sydow, 2016). The inclusion of the arts often makes the other disciplines more relatable to a broader audience of students and helps students see connections to the real-world (Kang et al., 2012). In work by Kant, Burckhard, and Meyers (2018), the researchers combined traditional native arts and crafts with STEM in order to increase interest in STEM studies and careers among high school girls. Through the use of culturally responsive enrichment, the activities deepened STEM interest and demonstrated relevance to the participants' daily lives and community well-being as a way of promoting interest in science (Kant et al., 2018).

Mentioned previously, Herro and Quigley's (2016) study had one teacher who used problem scenarios to engage her students. She created a real-world problem scenario (about earthquakes) and stepped back from dictating every aspect of the lesson. She saw that students were able to demonstrate their learning in “new ways” and this allowed “students who were previously disengaged from school and [instead] emerge[d] as leaders in their groups” (p. 18). These studies suggest that STEAM-based curricula produce a higher percentage and wider diversity of students interested in pursuing careers to support the fields of mathematics and science (Masata, 2014).

STEM careers are still incredibly homogenous; women and people of color hold only 28% and 10% respectively, of STEM jobs (National Science Board, 2014). To improve the STEM workforce to reflect multiple perspectives and knowledge, we need to alter the way we think about and teach STEM. To address the issue of attracting and retaining a diverse STEM workforce, the way in which we are teaching our students needs to be re-conceptualized to attract and retain alternative perspectives that will assist in solving the world’s most pressing issues (Quigley et al., 2017).

Motivation to Partake in STEAM

As mentioned earlier, STEAM remains a challenge for many teachers to integrate in school subject matter (Herro & Quigley, 2016). Based on current research, teachers seem to be conservative and not very confident in trying out STEAM methods due to ambiguity around STEAM goals and the efficacy of these methods. While no direct research has gone towards the analysis of teacher motivation towards STEAM, research has shown that teachers who experience higher student engagement tend to be more motivated in their jobs. In a study conducted by Sass, Seal, and Martin (2010), researchers examined teacher attrition and the causes of job dissatisfaction. They found that greater levels of efficacy related to student engagement tended to have fewer student stressors, and, in the end, reduced job dissatisfaction (Sass et al., 2010). Therefore, when creating STEAM lessons, teachers should create lessons with the intent of having engagement rather than traditional lectures. This will not only make learning more engaging for the students, but this will help teachers enjoy their jobs more. Although the enthusiasm for STEAM burgeons, researchers are still trying to determine ways in which to best support teachers in the classroom to help them create and implement meaningful STEAM curricula.

Theoretical Framework

This section provides the theoretical frameworks that guided this study. The frameworks included community of practice among STEAM teachers, constructionism among teachers' implementation of STEAM in their classroom, and reflective theory.

Community of Practice Theory

The concept of community of practice (CoP) is one of the frameworks used to support this study. CoP are "groups of people who share a concern or a passion for something they do and learn how to do it better as they interact regularly" (Wenger & Wenger-Trayner, 2015, p. 1). CoPs have various configurations and come in a variety of forms:

> Some are quite small; some are very large, often with a core group and many peripheral members. Some are local and some cover the globe. Some meet mainly face to face, some mostly online. Some are within an organization and some include members from various organizations. Some are formally recognized, often supported with a budget; and some are completely informal and even invisible. (Wenger & Wenger-Tryner, 2015)

In all these configurations, learning is social and situated and provides a unique system of joint enterprise through negotiated meaning, mutual engagement, and shared repertoire (Wenger, 1998). In establishing a CoP, members break isolation (Hadar & Brody, 2010) and set up a space for safe discussion, social and professional interaction, and negotiate their responses to conditions and goals of the community (Patton & Parker, 2017). Once established, all members work together to determine the practice and work to refine all its dimensions (Jho et al., 2016). Their mutual engagement involves the sustained interactions of each other and the roles and relationships that arise from their interactions; through collaboration they develop a shared repertoire of signs, symbols, tools, and language that are used as resources and have meaning specific to the community (Aguilar & Krasny, 2011; Kisiel, 2010; Wenger, 1998).

While much is known about CoP potential to enhance professional learning substantially less is known about the processes with respect to how they function (Patton & Parker, 2017). By examining how this community of teachers create STEAM curricula, researchers and practitioners can examine and gain a better understanding of educator learning. The study of teacher educator professional learning can be greatly enhanced when grounded in the distinguishing elements associated with CoP (Patton & Parker, 2017).

Constructionism

Constructionism was another framework used to support this study in evaluating how teachers implement STEAM in their classrooms. Seymour Papert, a protege of Piaget, the founder of constructivism, stressed the importance of engaging students in creating their own products as it enables students to participate in a web of connections to further their activity (Noss & Hyles, 1996). Papert believed that constructionism shared constructivism's connotation to learn as building knowledge structures irrespective of the circumstances of learning. Where they differ is that constructionism "adds the idea that this happens felicitous in a context where the learner is constantly engaged in constructing public entity whether it is a sandcastle on the beach or a theory of the universe" (Papert, 1991, p. 1). Constructionism has formally acknowledged its relationship to constructivism but has been careful to distinguish that it is not identical. Where constructivism places a primacy on the development of individual and isolated knowledge structure, constructionism focuses on connected nature of knowledge with its personal and social dimensions (Kafai, 2005). Constructionism articulates a more distributed view of instruction where learning and teaching are constructed in interactions between teacher and students as they engage in design and discussion of artifacts (Kafai, 2005).

Furthermore, “Constructivism gives prominence to how the learner’s logical reasoning and emotion-driven reasons for engagement are inseparable” (Mackrell & Pratt, 2016, p. 419). It is a framework for action. Constructionism is a set of prescriptions for pedagogical strategies providing focus and direction to the design of a learning environment (diSessa & Cobb, 2004, as cited in Mackrell & Pratt, 2016). Papert described how children needed to extensively explore to gain mastery so that he/she had a clear purpose to activate and be able to explain how he/she operated the tasks (Mackrell & Pratt, 2016).

This theory of constructionism is relevant to STEAM education in that it tells us we should be doing research in order to best create lessons that foster and integrate STEAM teaching. STEAM is responsive to increasing student engagement in multiple modalities which ultimately will assist a greater number of students than past STEM and/or in silo curriculums would have. STEAM allows students to gain content across various subjects and amalgamate the information to make impactful decisions for their future lives and careers.

Reflective Theory

The last framework that suits a STEAM curriculum is reflective theory. Reflective theory posits that as individuals continue their practice, they become aware of their implicit knowledge base and learn from their experience (Schön, 1991). The reflection process is a cyclic progression that refines ideas through experimental action (Ricks, 2011). Both John Dewey and

Donald Schön, champions of reflective theory, considered reflection as a process of developing and testing ideas in the crucible of action (Ricks, 2011). A summary of their general process is as follows (Dewey, 1981; Schön, 1991, as cited in Rick, 2011):

1. **Experimental event:** This event initiates the reflective cycle, perhaps an event that leaves the practitioner unsettled or curious.

2. **Idea suspension and problem creation:** At this point in the process, the practitioner must not be tempted to disregard the event by assuming an injudicious resolution to the anxiety of one or more possibilities arise. Instead, the practitioner should suppress the impulse to select a rapid explanation for the event and instead scrutinize the spontaneous idea for recognition of problematic characterizations of the event.

3. **Idea formation: ramify and refine:** This step is the creation of a possible solution. The uplift of ideas about the event to a realm of consideration provides the space needed for past experience, knowledge insight, thought, and reflection incidents. In this step giving mental freedom and time more evidence to be granted, more data to be found, and more understanding to develop, possible solutions can be considered, the best ones further developed, and refined in preparation for acting.

4. **Testing action with observation**: The last step of the framework is the action becoming the experimentation of the formulated possible solutions to the event. Ultimately the test could springboard the practitioner into deeper realms of reflective thought, if new puzzling observations arise during the testing phase, starting a new reflective cycle. Ultimately the experiment becomes a next experience that triggers further reflection.

5. **Cycle Continues**

This process is an active form of reflection that extends and links incidents into cohesive mental continuums as ideas develop through action. As described by Dewey, reflection is a multistage process of hypothesis formation connected to reflection by “testing the hypothesis by overt or imaginative action” (Dewey, 1981, as cited in Ricks, 2011).

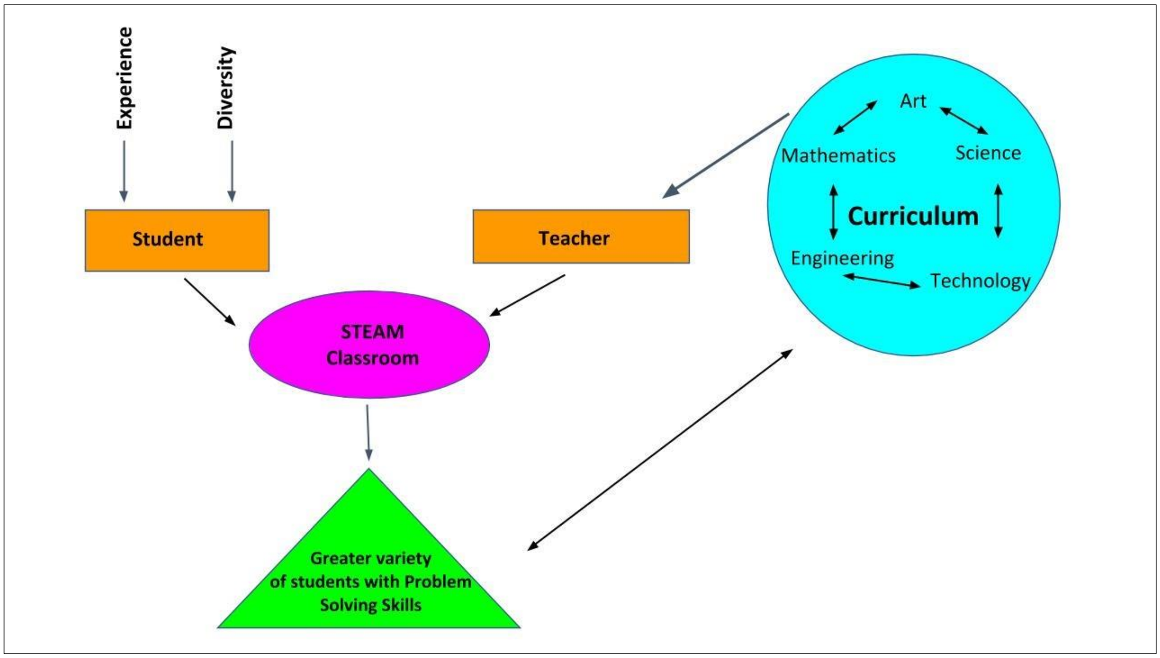
Donald Schön (1991) really developed the theory and went as far to further differentiate the types of reflection that exist. Reflection in action (RiA) and reflection on action (RoA), often understood in teaching to describe reflection during (RiA) and after (RoA) the teaching act respectively (Schön, 1991, as cited in Anderson, 2019). The overall end goal is that the educator develops and tests tentative theories by attempting to understand and change a situation to better help students learn (Ricks, 2011).

Explanation of Conceptual Framework

Based on the current literature and research questions, the conceptual framework (Figure 2.1) represents the relationships between the major factors underlying the experience of educators in creating a STEAM classroom. STEAM educators obtain knowledge from other STEAM areas (science, technology, engineering, the arts, and mathematics) in order to create interdisciplinary curricula which can then be used to facilitate the classroom in strengthening student learning. By building the STEAM curriculum from the lived experiences that students bring to the classroom, educators are able to facilitate meaningful and relatable learning that leads to developing students with problem-solving skills. In the long term, this sets students up to contribute back to the various disciplines and solve issues in those fields.

Figure 2.1

Conceptual Framework for the STEAM Classroom



This study aims to explore how STEM middle school teachers amalgamate the arts and STEM in their teaching to create successful and meaningful STEAM lessons. Teachers need to be equipped to help prepare students to see the connections between different parts of their education so they can apply them in, outside, and after school. By preparing teachers to deliver meaningful STEAM lessons, this can also lead to student success. This research describes the process by which experienced educators across different disciplinary content areas move from identifying a multidisciplinary question that is meaningful to their students to planning learning activities that guide students toward a solution. Participants describe not only their professional work products and the choices they made in creating them, but also their intellectual and social experiences as members of a professional team and witnesses to their students' work.

Chapter III

METHODOLOGY

Overview

Educators have a responsibility to recognize and cultivate multiple intelligences in order to prepare students for their lives after school (Darling-Hammond, 2010; Sousa & Pilecki, 2013); therefore, it is vital for teachers to develop lessons that will resonate with students and cause them to effect change. Through the implementation of a STEAM curriculum in an urban classroom, I suggest that experienced educators are able to move from identifying a multidisciplinary question that is meaningful to their students, to a plan for learning activities that will guide students towards a solution. How teachers guide students through this process is a focal point of this research. Understanding how teachers increase their engagement and knowledge as it relates to STEM and the arts in order to increase their capital in all classrooms, will ultimately allow them to help students be prepared for their future and the future of our society.

In this chapter, I outline the research design of this study. An overview of the research approach and a description of my role as a researcher are provided; the participants and setting, instrumentation, data collection and procedures, and plan of analysis are explained in detail.

Research Questions

1. How do middle school STEM and arts teachers create STEAM, an interdisciplinary curriculum?
    a. How is STEAM defined by middle school teachers?
    b. Why do teachers choose to create STEAM curriculum/lessons?

c. How do teachers bring STEAM into their content area courses?

2. How do STEAM classrooms function?
   a. How can teachers engage student learning in a STEAM environment?
   b. How does STEAM improve student learning outcomes compared to traditional classrooms (i.e., classrooms that do not teach interdisciplinary curriculum)?
   c. How do STEAM curriculum/lessons shape students' understanding of STEAM fields and their ability to transfer their learning across other learning environments or classes?
3. How do teachers reflect and act on their implementation and assessment of STEAM teaching in order to improve STEAM curriculum/lessons?
   a. How do experienced teachers reflect on their work to improve STEAM curricula?
   b. How do teachers use student work to guide their curriculum revision process?

Research Approach

To discover the ways teachers experienced creating and implementing STEAM in the STEM and arts classrooms, I used qualitative research methods. The qualitative approach seeks to understand human behavior and the context of the learning process to reflect the experience under investigation (Bogden & Biklen, 2007). Using qualitative methods can pose a challenge, as in any research study. It is important to recognize that qualitative research is sometimes considered less reliable or trustworthy, which stems from a belief that qualitative research is fundamentally subjective and therefore prone to bias (Davies & Dodd, 2002). When this occurs, it promotes a perspective that continues to keep communities marginalized. Recognizing qualitative research as a less reliable form of research encourages the limited access to the authentic stories and narratives.

The methodology of this qualitative study was an ethnographic case study approach which allowed me to focus on the cultural dimensions (ethnography) of educators planning, employing, and revising the STEAM model in their teaching (multi-cases). Ethnography is associated with an in-depth description of the customs of individual peoples and cultures. In this definition of ethnography, the term “culture” can include “what (behaviors), what they say (language, the potential tensions between what they do and out to do, and what they make and use, such as artifacts” (Creswell & Poth, 2015, p. 90). The values and benefits of this qualitative approach is that it enabled me to capture the creation and implementation of the arts as it brings value into the process of producing both scientific and artistic knowledge. From this research I hoped to understand what these cases among subject areas shared and how it promoted the deepest student engagement in STEAM education.

As I utilized ethnographic case study in this research, I had the goal of sharing the experiences of various teachers. Therefore, as we continue to study groups of people, we must value and encourage the use of qualitative research methods for researchers to position themselves as “insiders” as it relates to conducting research and understanding these populations in an authentic setting.

Field Setting

The study was conducted within an urban, public, selective, and competitive Science, Technology, Engineering and Mathematics (STEM) school. Approximately 750 students attend the school (grades 6-12). The school is located in New York City, New York, District 5. The school has an equal percentage of boys and girls and are selected based on how well they score on a school administered test. This school is a select STEM school that reflects the diverse demographics of New York City. The makeup of the student body is primarily Latino (45%), then Asian (19%), then Black (18%), and Caucasian (18%). Approximately 60% of the student body receives school lunch. The school is unique in that most students that come to the school are on grade level or above and are interested in STEM subjects. About 10% of the population, however, is placed in the school by the Department of Education and are typically below grade level. Students receive arts education in both middle and high school. Students study the fine arts for all three years of middle school and take music classes two of the four years (1 semester per year) of high school. Students also receive Career and Technology Education (CTE) instruction every year.

The school site was selected for this study for several reasons. First, the school is deemed a STEM school by the Department of Education and its partnership school, with a local university due to its unique offerings in these subject areas. The school has been implementing and refining STEM education since its inception in 2007 and has been recognized by the Department of Education for meeting all the standards for teaching STEM. Using a STEM school that has teaching practice in this type of curricula allowed for a more narrowed comparison. By observing teachers in the school also employing STEAM during lessons, I was able to compare the differences between STEM and STEAM. Second, having a diverse student population allowed me to examine how the arts amalgamated with STEM could affect students who are traditionally missing from STEM and the arts, as mentioned in the literature. Third, arts education is a required class for all students at the school. This ensured that all students were receiving some kind of arts education that could be referenced when discussing arts topics in other subject areas and vice versa. Additionally, having experts in the arts fields could provide arts resources for teachers when creating STEAM lessons.

Participants

In selecting the candidates for this study, purposeful sampling was employed. A typical sample was selected as it reflected the average person, situation, and instance of the phenomenon of STEAM (Merriam & Tisdell, 2016). The inclusion criteria for selecting the participants was having experience with the phenomenon being studied (Creswell & Poth, 2018) whether directly, or indirectly. As the participants already have familiarity with STEAM, they have found ways to successfully create curricula and employ it in the classroom. Participants also needed to have experience with STEM education as they would be able to compare the difference between these methods.

One science, one mathematics, one engineering, and one art teacher currently practicing STEAM were asked to participate in this study. With this diversity in teachers, as the researcher, I was able to assess learning from different vantage points. At the school where I obtained participants, the technology and engineering subjects are combined into one subject area. I wanted to understand the experiences of these four teachers in creating, implementing, examining, and revising STEAM. It also gave us insight into the experiences their students had with STEAM. All subjects that compile STEAM will be represented in this study to provide a broader perspective. Likely, the experiences with STEAM will be varied amongst the participants.

The study focused on STEM and arts middle school teachers who are currently practicing STEAM in their classrooms. The teachers from each classroom have each earned education master's degrees in their respective fields. As the participants already have familiarity with STEAM, they have found ways to successfully create curricula and employ it in the classroom. Participants also needed to have experience with STEM education as they would be able to compare the difference between these methods. The study focused on STEM and arts teachers from middle school teachers who are currently practicing STEAM in their classrooms. The teachers from each classroom have each earned education master's degrees in their respective fields.

Table 3.1

Summary of Participant Profile

Subject	Teacher	Years Teaching	Years Doing STEAM
Science	Katherine	12	8
Technology/**E**ngineering	David	12	11
Art	Isabella	4	All her life
Mathematics	Justin	10	3

Note. Table 3.1 is a summary of all participants and their background information. Please note their names have been changed for confidentiality purposes. In addition, at the school, technology and engineering are combined into one class.

Positionality

My positionality as both a researcher and active participant allowed me to guide and evaluate how STEAM was being implemented in the study. As a middle school classroom teacher that practices STEAM, I am well versed in the shared realities that come with being a classroom teacher and partaking in this specific type of curriculum. Having worked with the teacher participants for the past several years, this relationship allowed me to build rapport with them. Trust provided me the access into their STEAM process (i.e., creating, implementing, evaluating, and revising STEAM curriculum). In studying these teachers, I was able to empathize with them on the benefits and challenges that came with partaking in the process of this type of curriculum. This ultimately led to fruitful conversations about their experience and provided me with observations of their work from various vantage points.

In research, knowledge is often generated by academics who are disconnected from the classroom and make suggestions that are not always relevant to teacher practice. In addition to being a middle school teacher, I was earning my Ed.D. in Interdisciplinary Studies Program. This unique positionality as a research practitioner trained me in using professional development, theories, and pedagogical models in order to gather and use data in structured ways. While teachers reflect and evaluate their teaching methods, their lack of professional development in research methodology hinders their ability to sometimes engage in critical and deep learning around their curricula which ultimately can be detrimental in making effective change. Being at a research institution provided me access to outsiders who also offered feedback and methodological guidance during this research project.

Data Collection Method

I conducted interviews, questionnaires, observations, and focus groups with the four teachers. I also collected artifacts which included lesson plans, pictures of workspaces, and student work as shared by the teachers. After participants agreed to be part of the study (Appendix A and B), they were given a background collection sheet (Appendix C). This assisted the researcher in determining the best ways to reach them and gave the researcher some general information about their teaching experience (i.e., how long they have taught, how long they have been doing STEAM, etc.). They were also given a preliminary questionnaire (Appendix D). These questions examined teachers' STEAM practice in the classroom, to assess their involvement with STEAM. Once participants were onboarded and preliminary background information about them was collected, there were two phases to the data collection process:

Phase 1 was from October 2019 to January 2020 and Phase 2 which occurred from the beginning of February 2020 to June 2020. The timeline for data collection is summarized in table 3.2.

Table 3.2

Data Collection Timeline

Month/Year	Data Source
October 2019	• Recruitment Email • Informed consent • Background Collection Sheet • STEAM Questionnaire
PHASE 1	
October 2019 – January 2020	• Interview Question Guide • Planning Observation Protocol and Checklist • Classroom Observation Protocol and Checklist • Artifact Checklist
January 2020	• Focus Group Discussion
PHASE 2	
February 2020-May 2020	• Planning Observation Protocol and Checklist • Classroom Observation Protocol and Checklist • Artifact Checklist
June 2020	• Focus Group Discussion

Through the use of interviews, focus groups, observations, and artifact review, I explored and advised teachers over the course of one academic school year on how they created, carried out, revised, and evaluated STEAM in their classrooms. In the first phase of data, I focused on what the teachers were doing. I documented how they were planning, implementing, evaluating, and revising their STEAM lessons. This occurred during the first semester of the year (October 2019 to January 2020).

Interviews: Phase 1

Individuals who consented to participate partook in a 45 minute initial interview regarding their experience with STEAM education (Appendix E). All interviews were recorded, and transcribed, and reflective field notes were taken during and after the interview. Some interviews (e.g., Isabella and David) went beyond the scheduled 45 minutes but continued at the convenience of the teacher and the researcher's schedule.

A semi-structured interview protocol (Appendix E) was appropriate for this study, due to the varied nature of each individual's classroom culture, traditions, and interpretation of what constitutes art's behavior. By examining the lived experiences of teachers in STEM and the arts, the interviews allowed the participants to reflect and make meaning of their experiences (Seidman, 2013). A semi-structured interview allowed for space and time for the interviewee to express their thoughts by relating their experiences and observations; this built rapport with the interviewee and created an environment where participants felt free to disclose their authentic selves through their detailed responses (Alvesson, 2010). By comparing participants' stories and experiences, this study aimed to find differences and similarities between observed and implemented behaviors of the educators.

Interviews were conducted with one teacher from each STEAM discipline. As mentioned earlier, at the research site, the technology and engineering discipline are combined into one. Participants were interviewed individually. By comparing the stories of all the participants, I was able to explore the differences and similarities between goals and practice in different contexts and settings.

Fieldnotes and Observations: Phase 1

Throughout the months of October 2019 to January 2020, I documented what the teachers were doing in terms of their process of creating, implementing, evaluating, and revising STEAM lessons. I observed the participant's planning and implementation of STEAM using several Observation Guides and Checklists (Appendix F-Appendix I) during the research process. These guides and checklists were constructed from Merriam and Tisdell (2016). The first type of observation that occurred was when teachers were planning their STEAM lessons. The researcher was scheduled to attend one planning session (approximately 45 minutes) per teacher for each STEAM lesson they were planning.

Many participants (all except for Justin, the mathematics teacher) invited me to attend additional planning sessions for an average of three planning periods per participant. Teachers at the school are given designated planning periods, some of which overlap with other STEAM fields. During these sessions, the researcher used the Planning Observation Protocol (Appendix F) and Planning Observation Checklists (Appendix G). The lesson planning observations allowed the researcher to witness how teachers went about planning and creating their lessons.

The second type of observations focused on how the STEAM lessons that I observed planning for were implemented in the classroom. Initially, these observations were scheduled to last between one to three sessions (approximately 45 minutes each) depending on how long the lesson occurred. For lessons that went longer than the scheduled time frame, I attended the first lesson, a lesson in the middle, and the last lesson to see the various stages of the lesson. Since I also attended additional planning observations, teachers also welcomed me to see those lessons implemented as well. Unfortunately, due to time and scheduling constraints, not all implementation lessons could be attended for the additional planning observations. On the other hand, sometimes teachers deviated from their plans and invited me to lesson that I did not attend planning for (and sometimes they did not even formerly plan for).

Guiding the implementation observation, I used the Classroom Observation Protocol (Appendix H) and the Classroom Observation Checklist (Appendix I). The in-class observations allowed me to observe the behaviors and interactions of the teachers during the class. By observing teachers in their natural settings, intimate familiarity with the situation could be attained (Merriam, 2007). Field notes included verbal exchanges between all individuals, as well as practices that occurred in the planning time and the classroom, and connections between the two (Berg & Lune, 2012).

Evaluation of Artifacts: Phase 1

Mining data from documents and artifacts gathered was also employed. This allowed the researcher to understand what teachers make and use (cultural artifacts; Spradley, 1980). Lesson plans were collected to help give a snapshot into what, within a given topic, the teachers found important to emphasize, that is, personal perspective (Merriam & Tisdell, 2016). In addition, pictures of teachers' workspaces and layout of the classroom were taken to further understand what was valued during this process. Student work, provided and shared by the teachers, were also analyzed in order to determine student engagement, content knowledge gained, student experience with STEAM, and transferability of information. A checklist based on STEAM research assisted me in analyzing these items (Appendix J).

Focus Group: Phase 1

At the conclusion of Phase 1, January 2020, a focus group for all the teachers that participated in the study occurred. This focus group allowed participants to have a discussion around their views of STEAM. This gave the participants an opportunity to hear the views of others and refine their own views considering what they had learned. This refinement was a crucial component to assisting teacher reflection and implementation for the spring semester. It enabled the teachers to improve their own STEAM curricula development which we heard about in the second focus group.

Phase 2: Observations, Artifacts, Focus Group

In the second phase of my research (February 2020 to June 2020), I continued to engage with the teachers to help guide their growth and learning around the cycle of creating, implementing, evaluating, and revising STEAM curricula. As they continued the cycle I also observed and gave feedback. I simultaneously documented what they were doing and noted any changes they were making. I used the same observation guides as I did in Phase 1 (Appendix F-Appendix I) to inform my research.

Following all observations, I again evaluated any artifacts collected during this phase (e.g., lesson plans, teacher notes, student work, etc.) using the artifact checklist based on STEAM research (Appendix J). At the conclusion of phase 2, teachers came together for a final semi-structured focus group to again share their experiences.

Data Analysis Methods

Phase 1: Data Analysis of Background Collection Sheet and STEAM Questionnaire

A variety of qualitative analysis strategies were employed to analyze the data collected during the study. During the first phase of data collection (October 2019-January 2020), I employed the simultaneous data collection and analysis process discussed by Merriam and Tisdell (2016). The Background Collection Sheet and STEAM Questionnaires were the first pieces of data to be completed. These data pieces gave me some general information about how long these educators had been teaching in their content area and how long they had been doing STEAM. It also provided information on how they define STEAM and implemented it in the classroom. By having this preliminary information, I was better able to tailor my interview questions so that I could understand their intentions and thought process to creating, implementing, evaluating, and revising STEAM. Ultimately, it also contributed to helping me narrow my observations of teachers planning and implementation of STEAM lessons and evaluation of artifacts. They were coded for and used to guide the interview process.

Phase 1: Data Analysis of Interviews with all Teachers

I conducted one formal interview with each teacher before any observations. They were scheduled for 45 minutes; however, those conversations went well beyond that time for all participants. With Isabella (Art) and David (Engineering) I did follow up interviews at their request. For all participants, throughout and after the observation process, I conducted several informal interviews. Occasionally, I had follow-up questions that turned into longer conversations. During these conversations' teachers shared more information they felt was important to my study. Typically, they approached me, or they set up a time to meet post the formal interview. I coded the extra data gathered, I read and reread the data, made notes in the margins, and then separated them into memos capturing my reflections, tentative categories, hunches, and ideas. I used this information for the next round of interviews for the various participants. Between each interview, I would compare the information gathered and use it to inform the next interview and observation of all participants.

Phase 1: Data Analysis of Observations

Following the interviews, I re-read and added to my initial codes and then used them as a guide for observations with the Planning Observation Protocol and Planning Observation Checklist, which were produced in the natural setting. I was scheduled to observe the planning periods for one lesson (approximately one planning period per teacher), however, the teachers allowed me and/or invited me to observe more. Overall, I observed about three planning periods per teacher. Some of the planning periods were co-planning with multiple teachers.

After the planning observation, I employed both incident to incident coding and comparative methods. These methods allowed me to see and make sense of the observations in new, analytic ways (Charmaz, 2006). By doing this type of analysis, I obtained clues to follow and sometimes immediate new ideas. This allowed me to see first-hand how my participants managed their planning sessions without them having to tell me. After the first observation, I was able to compare against what was said in the interview and compare the execution of various teachers' planning. This comparison allowed me to code for similar events, define subtle patterns and significant processes, and compare dissimilar events. By employing this method, I gained further insights. I also used my findings from the Planning Observation to inform the Implementation observation.

I repeated the entire observation and analysis process for the Implementation Observation portion of the study. First, I used the Implementation protocol and checklist. It was coded for consistency (or inconsistency) between the interview, planning observation, and between each implementation observation of each teachers. I again employed the Incident to Incident method and Comparative method to garner insights and make sense of the observations (Charmaz, 2006).

I attended approximately three implementation observations per teacher. The observations lasted between 15 to 45 minutes, depending on my availability to observe the lessons.

Phase 1: Data Analysis of Artifacts

Throughout each teacher's lesson, I collected and analyzed a variety of artifacts. These artifacts included lesson plans, photographs of work areas, student work (as presented by the teacher), etc. Content analysis on these artifacts was used to confirm statements and hypothesis from the other data sources.

Phase 1: Data Analysis of Focus Group

At the conclusion of all the observations, in January 2020, participants joined me in a focus group. Questions were based on open and axial codes and memos from the background information sheet, questionnaire, interviews, observations, and artifacts from all participants. The open codes were preliminarily grouped (axial coding) then used to help further center the focus group. At the conclusion of the focus group, the interview was transcribed in its entirety and line by line coding was employed.

Once all the data was collected from phase 1 (background collection, questionnaire, interviews, observations, artifacts, and the focus group), I used a grounded theory approach to find themes within and across participants' experiences (Creswell & Poth, 2018). To accomplish this, I entered all initial codes done by hand into a Microsoft Excel spreadsheet. The data was sorted and resorted several times. Codes occurred until saturation was met, and no additional codes were necessary to categorize the data (Boeije, 2010). In the next section, I will explain the sorting and recoding process which occurred from January 2020 to February 2020.

Phase 1: Coding and Sorting of Data

In the first sort, “Initial Code Sort,” the initial codes were entered into the Microsoft spreadsheet in the following way: Code (Cell A), Quote (Cell B), Participant (Cell C), Data Type (Cell D), Page (Cell E), and Research Question (Cell F). The initial codes were then grouped together by similarity (Cell A). For example, in an interview, I coded phrases as “challenge to STEAM planning” and in observations I used similar coding language. When I sorted in the excel sheet (Cell A), these came together, and an initial category would be developed.

In the second sort, “Focused Category Sort,” I used focus coding to either combine or make new codes for the categories that developed in the “Initial Code Sort.” This allowed me to make the codes more directed, selective, and conceptual (Glaser, 1978). For example, one common code I had was “2 birds one stone” meaning that several subjects were being taught within one subject. I renamed this category “interdisciplinary” which was already a category in my “Initial Code Sort.” Once these new codes/combined codes were finished, I again resorted them.

In the third sort, “Axial Category Sort,” I used the new categories from the second sort, “Focused Category sort,” and within those categories devised sub-categories, converting some of the initial categories’ into new sub-categories. By reassembling the codes in this new way, I was able to build relationships around the “axis” of a category. This axial coding allowed me to develop subcategories of a category and showed the links between them as I learned about the experiences the categories represented. The subsequent categories, subcategories, and links reflected how I made sense of the data.

The final sort, “Theoretical Coding Sort,” occurred when I applied theoretical coding to specify relationships between the categories I had developed. This allowed me to “weave [my] fractured story back together" (Glaser, 1978, p. 72) through the arrangement of how they answered my Research Questions. These codes assisted me in telling an analytic story that had coherence and allowed me to derive themes found from the research I had collected. The links also provided by the codes helped locate areas that could be strengthened in the next round of data collection.

Phase 2 Data Analysis

In the second phase of data collection (Phase 2), which occurred from February 2020 to June 2020, I replicated the collection and analysis procedures for the planning observation, implementation observation, artifact collection, and focus group for the new lessons as selected by the teachers. Each teacher selected a new lesson for me to observe. As they did in phase 1, teachers invited me to see more than one lesson. In addition to the observations with the teachers, I planned with them and made recommendations (e.g., where to find resources, brainstorming on how to incorporate other fields, helping redesign their lesson to be more STEAM) and how to better shape their STEAM lessons based on my background as a STEAM educator. Analysis of this data collected in the second phase of the study paralleled the first phase.

At the end of the second phase, in June 2020, participants participated in another focus group and discussed their experience. They were asked guiding questions that were created from codes and memos from their initial interviews and observations from both phases. At the conclusion of the focus group, the interviews were transcribed in their entirety and coded. These codes along with all the other data that was gathered and coded for in phase 2 were analyzed in the same fashion as the focus group from phase 1. The codes were all combined and sorted into being able to provide theories to answering the research questions.

Table 3. 3

Data Collection Procedure for Research Questions

Research Questions	Data Collection Procedure
1. How do middle school STEM and arts teachers create STEAM, an interdisciplinary curriculum?	
a. How is STEAM defined by middle school teachers?	Questionnaire, Interview, Focus group of teachers
b. Why do teachers choose to create STEAM curriculum/lessons?	Questionnaire, Interview
c. How do teachers bring STEAM into their content area courses?	Interview, Planning Observation and Planning checklist, Focus Group of teachers, Artifacts
1. How do STEAM classrooms function?	
a. How can teachers engage student learning in a STEAM environment?	Interview, Classroom observation and checklist, Focus Group of teachers
b. How does STEAM improve student learning outcomes compared to traditional classrooms (i.e., classrooms that do not teach interdisciplinary curriculum?)	Interview, Classroom Observation and checklist, Focus Group of teachers, Artifacts
c. How do STEAM curriculum/lessons shape students' understanding of STEAM fields and their ability to transfer their learning across other learning environments or classes?	Interview, Focus Group of teachers, Classroom Observation and checklist, Artifacts
3. How do teachers define success in STEAM classrooms?	
a. How do experienced teachers reflect on their work to improve STEAM?	Interview, Observation of Teacher Planning and checklist, Focus Group of teachers
b. How do teachers use student work to guide their curriculum revision process?	Interview, observation of teacher planning and checklist, Focus group of teachers

Elements of Rigor and Validity

This study was examined through use of qualitative coding techniques, including member checking, peer review, and the triangulation processes (Creswell, 2013; Guba & Lincoln 1989). To demonstrate reliability, I utilized member checking as an approach to ensure that all the participants interviews were being interpreted within the appropriate context and not solely through my experiences, which I recognized may not entirely be the same as the participants (Shenton, 2004). Tentative interpretations were presented to the participants for validation and clarification of interpretation.

Peer review occurred in conjunction with fellow colleagues and classmates throughout the process. Classmates were given samples to code independent of the researcher. Their findings were then compared with that of the researcher. Colleagues of the researcher also had discussions around what they observed and that of the researcher. If they took notes, their notes were also compared to that of the researcher. Overall, the reviewers read the data and determined codes and emerging themes and then compared it with those from me as the researcher.

Triangulation was also used by collecting and using multiple sources of data (background collection sheet, questionnaire, observation, interview/focus group, and artifact data). For example, when determining how each teacher defined STEAM, they were asked in the questionnaire to write out their definition, and they were asked again in both their interview and the focus group to define STEAM. In the observation, their actions were observed and compared against the other two data sources (questionnaire and interview/focus group). The various sources, such as the ones provided in my example, allowed me to triangulate and compare findings to ensure that they corroborated one another. The use of multiple research methods to collect data was employed to ensure the validity (the extent to which research findings are credible), reliability (the extent to which there is consistency in the findings), and trustworthiness of this research (Merriam & Tisdell, 2016).

Validity. Utilizing multiple research methods such as focus groups, individual interviews, observations/field notes, a questionnaire, and artifacts allowed me to triangulate and compare the findings to ensure that they corroborate one another. In addition, attempting to clarify researcher biases and assumptions by having participants re-read their interviews and observation notes and spending two semesters also helped to contribute to the validity of this study.

Some validity issues and possible strategies for handling these issues were considered. First, data collection methods were piloted and modified in the Summer of 2019 prior to use in this study. The pilot was conducted with STEAM high school teachers who worked at the same institution. The aim of piloting materials was to ensure that the instruments elicited responses that were related to the research questions. Second, during interviews, my presence might have led the participants to answer questions they deemed socially desirable responses. Throughout this process and as mentioned prior, member checking was employed to measure consistency and to cross-check responses. Some questions were also presented in other formats (i.e.,, questionnaire). As the researcher, I was mindful that the protocol questions were not leading in nature. By providing enough open-ended questions and being aware of certain questions, I worked toward ensuring that responses would be influence free. Lastly, as the researcher had some connection with the participants as we work in the same institution. This positionality was considered when analyzing data. Previously, Table 3.1 illustrated how the methodological design was used to answer the research questions.

Ethics and Reflectivity

In conducting this study, I considered that ethical issues arose in qualitative research. Due to the sensitive issues that may be uncovered from interviews and observations, the research was conducted in a manner that caused the least possible harm to the participants. I worked towards developing trust with the participants and exercised discretion at all time. Following the approval of the Institutional Review Board, the participants voluntarily signed the Informed Consent form (Appendix B) to participate in the study before interviews or observations commenced.

Confidentiality and anonymity were concerned with the identification and dissemination of the data, and pseudonyms were used. When participants participated in the focus groups, they were with other participants; therefore, it was impossible to be 100% anonymous and confidential. All participants, however, were reminded before, during, and after the study that information discussed should not be shared with others not in the study and that it was a private setting. As previously mentioned, I knew the participants as colleagues working in the same school building. In addition, while participants received a pseudonym, parts of the data may be apparent in linking them with responses.

All written materials were locked in a desk drawer in a locked office. Any electronic or digital information (including audio recordings) has been stored on a computer that is password protected and encrypted located in the researcher's office and only accessible by the researcher. After audio recordings were made, they were immediately transcribed, and the original audio-recordings were stored on a password protected server. The interviews were audio recorded and transcribed by the company "Temi." The company agreed to sign a non-disclosure agreement to protect the privacy of the participants. Each participant was assigned a de-identification code composed of random numbers. They were stored on a password protected computer on a secured network. Any hard copies were locked in a file drawer in the office of the researcher and only accessible by the researcher herself.

Conducting a qualitative study allowed me as the researcher to deeply explore the lived experience of the participants while the analysis provided the audience a rich understanding of teachers doing STEAM in their classrooms. The study, however, does not offer an analysis of the experiences of a broader range of teachers participating in STEAM due to the participant size. While the data collected may be transferrable, this study is not comprehensive enough to engender all levels of education.

Data collection and analysis offered a snapshot of how teachers experience the process of doing STEAM curriculum rather than a longitudinal perspective. The process and resources that teachers used to create, implement, and revise STEAM were complex and varied. There were certain elements in their processes that remained fluid and consistent, but the scope of lesson topics was extensive and required teachers to be flexible in learning and teaching the topic based on their individual experience.

While the researcher aimed to realistically depict the experience of these teachers, I acknowledged my bias to STEAM education and thus, my understanding of their experiences was understood through a framework of my participation in STEAM education. While the interviews and focus groups sought to deepen the understanding of the participant's perceptions, I recognized issues inherent in conducting the interviews, in so much that interview questions, or the delivery of those questions, might unintentionally influence the participant's response.

Finally, as recognized by qualitative research, participants may respond in a manner that they perceive as desirable to the researcher but not accurately representative of the authentic lived experience. While sharing the experience of STEAM teachers, I recognized that it was their experiences, and I was less qualified to communicate their lived experiences which ultimately impacted the study as a limitation of this study.

In the next chapter, findings are organized as individual cases of each of the teachers. Each case opens with background information about the teacher participant and how they define STEAM education. The presentation of the participants moves from a lesser advanced practice to a more advanced practice of STEAM. Following the introduction, each case is broken into how they create STEAM, what they do to implement it in the classroom, and closes with how they reflect and revise to restart the STEAM cycle. Closing the chapter is a snapshot of how this STEAM community of practice came together to develop two grade-wide STEAM projects. It breaks down, from the beginning, their process and what they were able to achieve.

Chapter IV

FINDINGS

Participant Profiles

In order to address the research questions, data was gathered and triangulated from several sources: interviews, questionnaires, observations, focus groups, and collected artifacts (Wolcott, 1994). These data were analyzed in light of the research questions and in accordance with the theoretical frameworks: community of practice, constructionism, and reflective theory, are presented earlier. The first part of this data analysis is an amalgamation from the various data sources and provides an overview of each individual teacher and how they create, implement, and revise their STEAM curricula (Wolcott, 1994). The order in which the cases are presented demonstrates a progression of STEAM practice complexity.

David: The Technology and Engineering Teacher

David is a middle and high school engineering teacher with 12 years of teaching experience. In addition to his course load, he runs several engineering electives that culminate in preparing students for the annual Future Cities Competitiona non-profit national competition sponsored by various engineering organizations to promote technological literacy and engineering to middle school students. Prior to his career in education, he owned and directed a construction business. His company did apartment remodeling (kitchens, bathrooms, joining two apartments on the same floor, and "duplexing" two apartments) in addition to commercial spaces and terrace carpentry. Outside his job, he plays piano, a hobby since childhood. He also enjoys listening to and attending classical music concerts with his wife, including an annual tradition of seeing a live performance of the Brandenburg Concerto by Bach in the City.

David reported that he has been practicing STEAM for 11 years. He defined STEAM as the following:

> [STEAM] differs from STEM in that there is also an equal emphasis for art. So, since to me as an engineering teacher, I incorporate science, technology, and math as the building blocks of engineering. So, the inclusion of art is how math, science, and technology can be employed to solve human problems where the solution is also aesthetically pleasing. (Interview, December 2019)

Creating STEAM

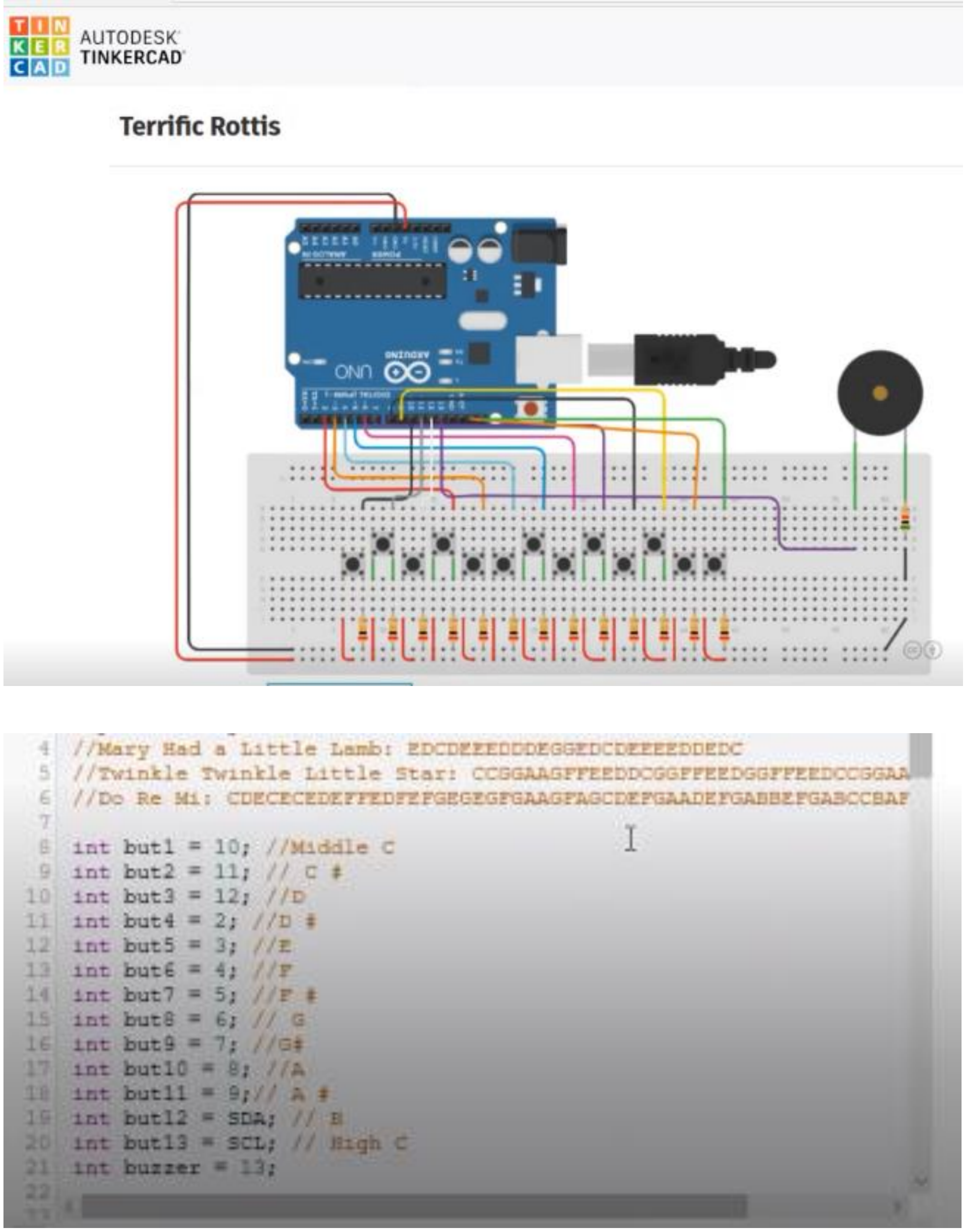
In creating STEAM, David reported that he does not have a formal process. "I just do it because I've been doing it all my life anyway [and] it's part of me." He continuously referenced his experience as an engineer and reported that "I teach students by showing them the process that I take and have taken when I engineer things—lots of trial and error." Based on David's observations, STEAM was shown in various ways. One technique that he had is that when he got ideas for a lesson, he scribbled them down on pieces of scrap paper, which were generously spread around his classroom and home. He then used these notes to create the new lessons or expand on old ones. He reported that a lot of the time the ideas just came to him and he went with it, even if it was just the night before. Most of the time, he planned alone unless another teacher suggested planning together. He reported that his best ideas came when he is up was the Catskills where he owned a second home to escape the city: "with the quietness of the area and the serene landscape I can clear my head and then the ideas just come to me." David had found a space where he could initiate his reflective cycle which allowed him to think about his lesson and how he can further refine them. He developed possible solutions and refined them through experimental action until he is satisfied with the outcome. Once developed, he continues his teaching until the next puzzling observation occurred.

Another way he created STEAM lessons were following up on student interests. He explained that allowing students to "artfully find creative things to do" would get them engaged in learning engineering. In one unit, students were learning how to build circuits through the Arduinos program, an open-source software that allows individuals to build digital devices. Several of his musically inclined students saw it as an opportunity to build a digital piano as they were very interested in music (Figure 4.1). The students reported in a presentation they made to David (which he formally invited me to come see):

> So… for our design we actually….we actually……we all decided this circuit that was a piano one and [ ] copied it and we were all just thinking of ideas to make the piano…like….not the regular kind…like more advanced piano so we can play on it….and like revise it…so as you can see, we modified the code so there are a couple of songs that the player can see. A couple notes around the Hertz's of each notes. Also, we added a lot more buttons and like [ ] just said. Before all the buttons were at random frequencies and we made each button emit a frequency that matched the note….and we also added at the top of the code some songs you can play um… Mary Had a Little Lamb, Twinkle Twinkle Little Star… and Do Re Mi…. (Observation of David, May 2020)

Figure 4.1

Arduino Piano



Note. Several students in David's Engineering class engineered a novel digital piano. They started with the basic layout of a standard piano then used circuits and buttons (via creating code) to engineer new sounds. After creating the instrument, the students programmed it to play several songs.

By allowing his students' interest to direct their learning, he achieved his goal of "developing independent, self-motivated, collaborative, and life-time learners" (David Interview, November 2019). His students not only manufactured a product that they devised and constructed on their own, but they even took it a step further to discuss the possibility of continuing this project and exploring how they could engineer other instruments and new sounds through this program. This STEAM project is in line with constructionism which allows students to create their own products to help them grow and develop connects to the activity they are doing in the classroom and beyond. These students learned about the Arduino program through construction of a product that they hope to further develop past the classroom assignment.

While it can be beneficial to use the arts to bring students into engineering, good STEAM practice is equally integrating two or more subjects into the lesson. Based on my research and findings from the literature, I believe that STEAM lessons where the art can be taken away and the main goal of the lesson can still be achieved without it is not considered STEAM. For example, in one of David's lessons, he was teaching students about the movement of electrons. He had them design their own electron mask which they wore mimicking the movement of the electrons. Since the lesson was focused on the movement, this would not have been considered a STEAM lesson because the students would still be able to mimic the movement even without their artfully designed masks (Figure 4.2).

Figure 4.2

Electron Masks

Note. Electron masks were designed by the students to be worn while mimicking the flow of electrons. While the masks are artfully created, they do not help contribute to the understanding of how electrons move. Without the masks, one could still learn about the particular movement of electrons.

In his various processes to create STEAM, David reported that he always consulted the Engineering standards, ASEE Engineering Standards (Appendix L), and sometimes he used the Next Generation Science Standards (NGSS), which have an engineering component built into it. He noted, however, that “the NGSS standards are not at all close to what engineering is supposed to be. The ASEE standards are much more advanced.” Despite his thoughts about NGSS, he had them next to his desk and glanced at them before creating or improving lessons. When planning David also used past resources to reflect on student work and his teaching. These resources were guides that helped him reflect in order to improve lessons year to year or even sometimes class to class. He also saves past worksheets and handouts to review when developing or re-developing lessons. Sometimes they are uploaded on his computer and other times he has hard copies in various piles throughout his classroom. David relied more frequently on hard copy handouts rather than electronic versions. Once he located where his handouts were, he typically used them as a framework and made modifications based on which process from above he decided to use.

Lastly, in some instances, he held on to past student exemplars to help guide his instruction. By examining and reflecting on student work allows him to come up with solutions to challenges students had in lessons so that overtime they become more refined. Throughout this entire process, he plays classical music when he works. Some of his favorites include Bach and Rachmaninoff.

Implementing STEAM

In implementing his lessons, he takes a global approach by incorporating aspects of both engineering and real-world applications as they relate to the students' lives and on a more general and sometimes international level. He sets some of his lessons up as scenarios where students must "get the job" to succeed. In one lesson, there is his fictious company, "Penny Pinchers," who sponsors a competition for creating a new set of gym stairs. The teams of students work together to design a set of stairs, create a materials and cost list, assemble a model of the stairs, and finally pitch the product (the stairs) to the company "Penny Pinchers." The STEAM aspects of working collaboratively using other fields (i.e., math, science, art) to create the stairs and the process of design allows students to learn deeper through the construction of a product. In addition, simulating a scenario like real-life companies vying for project contracts, teaches students a lot about the reality of the field. Like professional companies, the "student companies" are expected to compete with their classmates to come up with the most efficient product and cost-effective plan to succeed.

Another component he implemented in his lessons is through drawing on relationships between everyday products that students use and how engineering plays a role in their development. For example, as part of the gym stairs competition unit, one lesson within the unit had students examine the stairs in Morningside Park. These stairs are located near the school and are often used by students when traveling to and from school. He started the lesson by asking students to think about how easy or difficult it is to travel up and down the stairs. From there he used their experience to further analyze what is good and bad about them. In addition to having them reflect on their own experiences he guided them through thinking on a more global scale and the restrictions others, who are designing stairs, may have to overcome (i.e., he discussed with students that in Europe buildings were very narrow and the restrictions that came with that challenge). David asked students to "think about the dimensions of the stairs…what is the material they are made of…look at the height, look at the width—measure it!...Is each stair equal in length and width?...How does this all compare to other types of stairs?" By using their own experience and guiding them in thoroughly examining a set of stairs, David assisted the students in being more critical about how to design and construct their own gym stairs for the project.

When delivering lessons, he typically uses his self-made white board to explain the lecture aims. He likes to diagram out, piece by piece, what he expects the students to do. Sometimes he also holds up samples for them to look at. As he lectures, he likes to draw connections with other subject areas though it is difficult to gage whether the students make the connections between the other subject areas. For example, within his unit focused on the construction of stairs, he referred to concepts taught in math and science like height, rise, and slope, which are required to determine the slope of the stairs. During the discussion students seemed to recall concepts and were willing to share during discussions; however, David only gave them a few seconds to respond and sometimes did not let them finish their thoughts. This was contradictory to what he reported in his interview in which he stated that he "allowed time for students to explore and share their ideas" (David, Interview, 2019). In addition, when there were mathematical computations involved, he had students input the data into a pre-made spreadsheet that automatically did the calculations for them instead of allowing them to apply the formulas they had learned in mathematics class. He reported that due to time constraints and a fear that students would miscalculate he devised this pre-set excel sheet. While cross-curricular content does appear in the class, it is unclear how deeply students are making the cross-curricular connections between subjects.

During the STEAM lessons, David helped the students make sense of the content by providing them with hands on experience in doing the process themselves. For example, during one of the engineering lessons, students had to work together to construct a model cathedral. One of the students, who was classified as a very low functioning special education student and rarely participated, constructed her own cathedral and modeled it after one that the class visited. In addition to fully constructing a model on her own, she took it further by designing the outside in various themes like was done at the Cathedral of St. John the Divine, the cathedral that she and her classmates visited (Figure 4.3).

Figure 4.3

Cathedral Created by Special Education Student

Note. This cathedral was constructed by a special education student who is considered very low and is usually disengaged from class. Like the Cathedral at St. John the Divine, she made a theme for the stained-glass windows.

This modality of learning provided by STEAM not only assisted the student in better understanding the construction of the cathedral but also provided a way to express herself and demonstrate her learning.

Furthermore, David sometimes makes time for students to try out concepts. He provided them time in class to do hands-on learning through the incorporation of designing, sketching, and building. During one of his gym stairs lessons I observed, the students sketching models of their stair designs. I also noticed that students are typically divided into small groups which seems to mimic how the engineering field operates. As mentioned by David, who was a professional in the field, “engineers are always collaborating and sharing their ideas.” While David acknowledges and strives to build and maintain a STEAM classroom, what he reports and what is seen does not always align.

Reflecting on STEAM

At the end of each lesson, David shared during his interview, that he does some unofficial reflection primarily focusing on the energy of the class. When students were louder and high energy during classes, he considered the lesson to be less effective than when the students were quieter. He discerned that the less chaotic the students, the more engaged they would be as they seemed to be focused on the task at hand. Upon reflecting on the higher energy classes, David thought about how he could quiet them down by getting them more engaged. Unfortunately, due to the timing of this study, observing how bringing the energy down to make students more engaged was not seen. It was noted, however, from my various observations of his class during both phases, that while students were sometimes quiet, they were not always fully engaged. For example, in the lesson previously mentioned when David was lecturing on the mathematics of constructing stairs, some students were playing with toys and having personal conversations.

This made it difficult for the participant and the observer to agree that while energy would have been considered low, the students were not entirely engaged with the task at hand. Further supporting this evidence was when it came to sketching their model, students struggled with accurately depicting the dimensions. When observing the students, myself, their low energy seemed to be linked to disengagement which was evidenced by their lack of attention to detail. Several of the students I had observed before in this and other classes and had seen them do similar work where they were more accurate.

David does not have a formal revision process, but he typically does more in-depth reflection if he decides to re-use and revise lessons the following year. During the planning process, he will pull out the materials used last time he did the lesson and reflect on what happened. He thinks about the materials he used and the process he went through. He also thinks about the time and what he needs to cut out from prior lessons (or lack thereof). Repeatedly during my observations, he would make statements like "I used to do this in more depth, but I have less and less time with the kids" (David Interview, December 2019). As mentioned in his STEAM process for lesson planning, David thoroughly examined past lesson handouts and resources to determine what was successful while teaching STEAM. He also keeps a few student samples that can help him gauge how well students did or did not grasp the material.

Justin: The Mathematics Teacher

Justin is a middle school mathematics teacher with 10 years of teaching experience. He is the Department Chair of the Mathematics Department at the school and has held the position for the past four years. In addition to his teaching duties, he runs a mathematics extension class for students interested in pursuing mathematical topics. For a few years in his career as a math teacher, he was part of Math for America, a professional development "model based on the belief that collaboration, continued learning, and genuine respect enables teachers to grow professionally and provides long-term career satisfaction" (Math For America, 2020). For the past few years, he has been taking undergraduate and graduate level courses in mathematics and computer science at local universities. Prior to becoming a mathematics teacher, Justin had a short career in consulting. He sang in choir during his undergraduate and has been playing piano recreationally since he was in elementary school. Outside of the classroom, Justin enjoys visiting the local museums, attends performances at Lincoln Center, and is an amateur astronomer. Justin reports that he has been practicing STEAM for 3 years. He described STEAM in the following way:

> STEAM is an interdisciplinary approach to answering questions and solving problems that draws on ideas from science, technology, engineering, the arts, and mathematics. It's an approach that's represented in many design problems, since objects or systems that interact with people need to be both functional and aesthetically pleasing. STEAM is a nice way for students to culminate and bring together their learning from different classes. (Justin Interview, November 2019)

Creating STEAM

Justin has never received any formal training on STEAM but takes a trial-and-error approach to determine the best methods for creating and delivering lessons. When creating curricula, Justin first determines the goals his lessons aim to achieve (with priority made towards the state required mathematics standards—Appendix M), as he is a backwards planner. When planning for STEAM lessons he typically turns to academic and museum resources to guide his lesson development. If available, he also tries to visit and study examples of the products he is trying to have the students create. By examining the topic from various vantage points, he can ultimately have students examine the dialogical relationships between the artifacts and mathematics.

Next, he contemplates how he can support students in using mathematical tools, thinking, and concepts to reach those objectives. An example of this process occurred when Justin spearheaded one of his major STEAM projects with the students which focused on the students creating sundials (Appendix N). The idea to do this was initially influenced by Katherine the science teacher who was doing a unit on the moon. His process was to start at the library and learn all he could about the topic. From there, he consulted an expert, the prior art teacher, who is also a former math teacher and current architect. She directed him to more resources and examples he could visit. He did so and discovered that there were several within the community that were examples he could use for himself and take the students to see. This allowed the students to understand not only the mathematics of how to construct and use a sundial, but also its history and the context to which they were invented and used for.

For Justin, one of the biggest motivations for creating STEAM lessons is the social learning and collaboration with his colleagues. As mentioned earlier, Justin frequently visits Katherine’s (and his other colleagues) science classroom during instruction for informal observations. As reported in his interview and as observed, he also engages in discussions with the science teachers after lessons. He was also an active participant in grade team meetings when it came to devising joint interdisciplinary curricula. In addition to working with his colleagues, Justin is also one to reach out to outside organizations and professionals to learn more about a subject.

Without the support of his colleagues, Justin is more reserved and almost hesitant to teach STEAM. His perception that it takes a lot of time, requires much involved planning, and having the utmost trust in students (which usually comes at the end of the year). This hindered his ability to try it on a smaller scale within his own classroom. He added that, “I connected my work with students and my own personal interests as it’s a big investment. If you don’t feel like you’re getting something personally from it, it’s a lot harder to sustain.”

Implementing STEAM

In any domain, experts have multiple representations of key ideas. Justin uses STEAM as a method to engage students in building multiple models and reference frames around key mathematical concepts. For example, when students learned about least common multiples (LCM) in a traditional mathematics class, it was typically explained through times tables and number lines. In Justin’s STEAM classroom, he used spirographs (Figure 4.4), which are geometric tools that produce mathematical roulette curves of the variety technically known as hypotrochoids and epitrochoids, to supplement his teaching of the same concept.

Figure 4.4

Spirograph

This allowed students to be more engaged as they used their kinesthetic senses and transferred this concept to other environments, as they are learning about LCM not only in the way mathematicians used it but also how LCM are part of our everyday world. In addition, because it was more hands on, as they needed to construct the product, they were constantly engaged.

When practicing STEAM, Justin's projects extended beyond the classroom to involve real-life applications and skills. One such skill was the collaboration with peers and/or organizations. Many of Justin's lessons engaged students through working together as the tasks were challenging and time consuming if done alone. Another skill found in Justin's STEAM classroom is authentic discussions during the practice of a real-life application that garners feedback which can lead to improved outcomes. An example of the acquisition of these skills was seen through Justin's sundial project. In the implementation of this project, students worked together to research and build their sundials.

During the construction phase of their sundials, they needed to collaborate with their peers in order to design, create a plan, and make calculated measurements to build their sundials. They had to heavily discuss their choices and debate whether their data was accurate or not during the testing and analysis part of the unit. As the students learned in their other STEAM subjects (science, art, and engineering), the skill of collaboration and sharing information was pertinent to the success of all professions in those fields as it is impossible to do anything by oneself.

An additional real-life application skill gained from this unit was that of critical thinking. After the construction, students tested how their sundials worked. During the project students had to determine the optimum placement of their sundials so they could collect data and record information to complete the task of comparing solar time to clock time. Similar to real-life, the students had to critically think when challenges arose to completing this data collection task (e.g. the sun moving, the wind moving the gnomon in the sundial, not having enough compasses to determine where north was, etc.). Aspects of this project were transferable to other STEAM subjects and occur in many professional fields.

To peek student interest, Justin sometimes tied lesson content to students' personal lives. As part of the construction of sundials, Justin taught students about their history as well as their own. He explained that sundials played a significant role in various cultures. To honor the significance and further educate students on the context of sundials, he had the students decorate them with a motto about their family, modeling the work of the original creators of sundials. While Justin observed the students during this process, he noted an unexpected challenge that arose "the students unexpectedly had a difficult time marking the movement on their sundials. One of their biggest challenges was that they were very concerned about damaging the sundial product they had created, especially the familial decorations."

To engage students, Justin tried to choose topics that had some relationships to his students' lives. Often, he used familiar community connections to bridge mathematical concepts with student interest. As an introduction to the sundial project, he took students on a field trip to visit and examine several authentic sundials at the nearby university. This allowed them to closely examine a genuine product, but also gave them information on how to construct their own sundial (employing hands-on learning). For another set of STEAM lessons, Justin made ties to another familiar institution and the cultures of some of his students. He created a set of lessons focused on the Islamic Art Collection at the Metropolitan Museum of Art. He first taught them the foundations of geometry as specified by the mathematics standards. Once they had mastered those, he took them to the museum where he could relate what they learned to the everyday practice of the society of Islam. At the museum, the students saw how these geometric shapes were used in everyday objects by the people of Islam (and even in their own homes). The designs were apparent on their pottery, rugs, architecture and more. In addition to the mathematics connections made, the students learned about the historical impact geometry had on everyday society. At the conclusion of the lesson, students created their own geometric patterns which demonstrated not only their understanding of mathematics but also applications for these patterns.

Justin's implementation of STEAM engages students beyond the typical in silo mathematics classroom. While he had discovered many ways to broaden student learning through STEAM, he is sometimes cautious when doing these lessons. His mathematics class is tied to a state exam; therefore, most of the major STEAM lessons were taught at the end of the year or post the examination period. While his STEAM lessons do cover content found on the state exam, Justin reported during his interview, that STEAM lessons take more time, and he is scared that he will run out of time to cover other topics. He also reports that at the end of the year, one of the exams are over students and teachers like himself are less stressed and have more freedom to take curricular risks. As he continues to do STEAM, the hope is that he can use this teaching style more fluidly throughout the year to help students find deeper meaning in concepts.

Reflecting on STEAM

> When reflecting on his STEAM lessons, Justin doesn't have a formal process and admits that this is probably a weakness in my teaching, but I always have a formal reflection and improvement process. When I go[ ] back to a unit or lesson in the following year and like I'm looking at all the materials that I had before, I now have the added experience of having done that the previous year. [ ] I make changes and tweak things and add things and revise things. (Justin Interview, November 2019)

There is the consideration that children change from year to year, but his past experiences teaching STEAM allowed Justin to tweak and better predict what students will struggle with regardless of the different materials or different scheduling constraints from year to year. “So, I think a big part of how I improve my lessons is just drawing on my accrued experience.” From lesson to lesson, Justin thinks about the unresolved issues and possible solutions for the next time he does the lesson. Every implementation is a new test that usually furthers deeper reflection but also further developments of his lessons.

In addition to his experience, a major point of reflection for him is also looking at and evaluating the students’ work. He tries to understand each student’s strengths and misconceptions. To do this, he uses rubrics that he makes prior to the lesson based on aspects of excellence in the quality of authentic objects, as opposed to what the students did. He draws on both what he deems and what the literature deems as important for the students to master. From there he can evaluate how closely the student was able to match the authentic product. “Ultimately it’s about what students know and can do, but the way that they show that is in the objects they create.”

Isabella: The Arts Teacher

Isabella is an art teacher with four years of teaching experience and a lifetime of STEAM experience. She was educated in Italy where, as she reports, all learning takes a divergent approach, “There are no boundaries. Everyone can fix everything.” After her studies, she worked as a professional artist and transitioned into the movie field as a production designer for movie and theater sets. Her background has allowed her to bring a unique view to education and has contributed greatly to her expansion of the STEAM field. Isabella reports that she has been practicing STEAM since the beginning of her career both in and outside of education. She defines STEAM programs as “…exploring opportunities where art fits in the STEM arena. The purpose of STEAM should not be so much to teach art but to apply art in real situations. Applied knowledge leads to deeper learning."

Creating STEAM

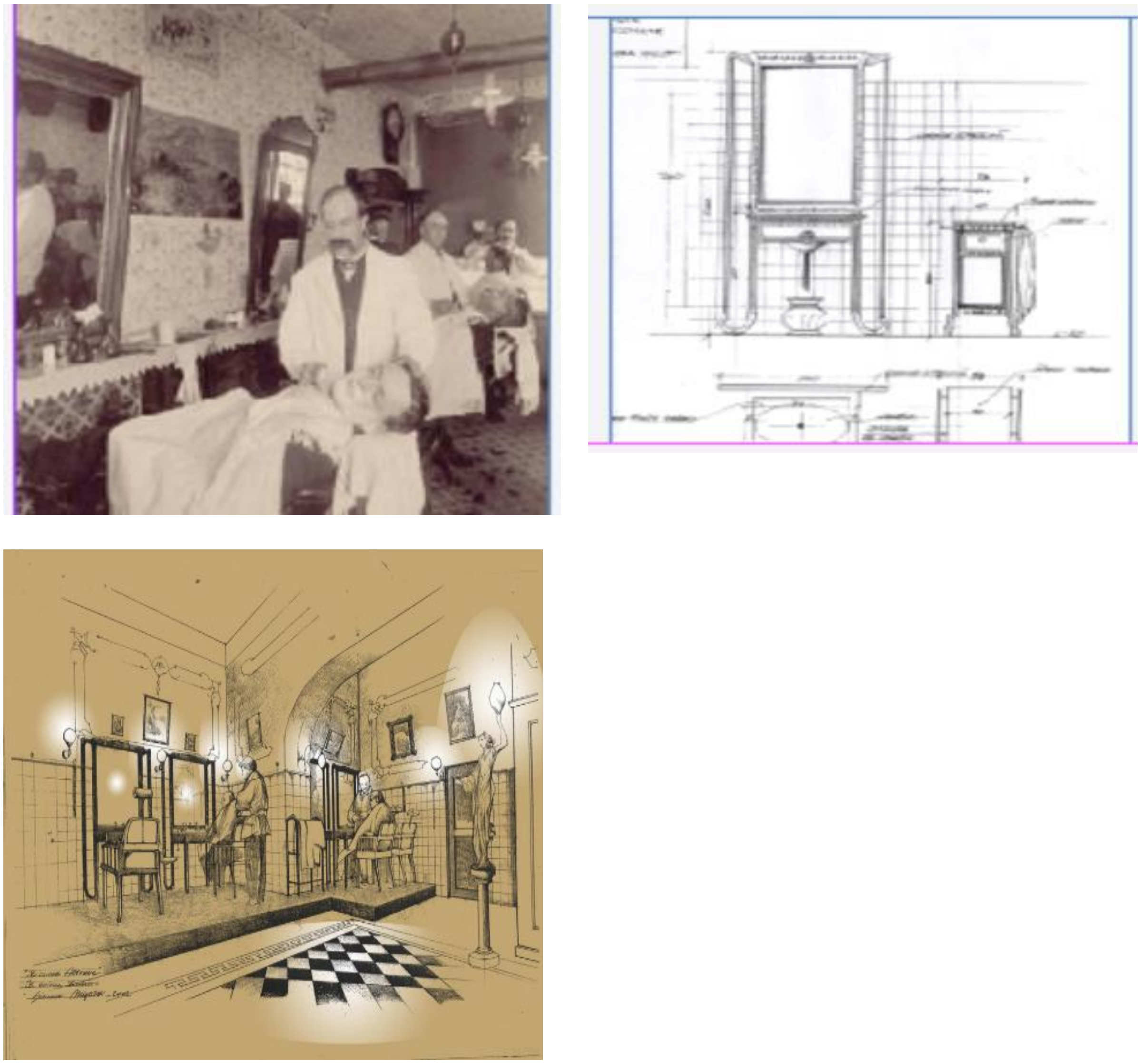
Similar to her upbringing, Isabella's approach to teaching STEAM is building a classroom that fosters divergent learning. For example, in art the teacher shared:

> So always my approach was, you know, by going through divergent learning. So basically, art like in a movie, there is a portion of like going through research to create a final image. So, there is a creative process in which includes all the artist. For example, just like illustration comes at art, very, very soon you have to go through, for example, math and geometry because you have to go through blueprint. So, you have to do a floor plan elevation. Otherwise, your fantasy would never be a reality. So, my idea, after many years of experience, I go from fantasy to reality. So, apply your knowledge to your personal perspective but make these real. Not just imagination, how you transform somebody that's just a dream and a dream you can actually walk through! (Isabella Interview, December 2019)

Bringing in her firsthand experience allowed students to have a knowledgeable resource outside of the traditional classroom setting and in a more authentic experience. See sample of Isabella's process (Figure 4.5).

Figure 4.5

Isabella's Process as a Movie Set Designer



Note. Isabella's process as a movie set designer to go from fantasy to reality. First, she sketches out a blueprint, then a draft of the setting, then recreates the setting using physical objects.

To start her planning process, she uses the National Arts Standards and New York State Standards (Appendix O) to build a general foundation for the school year. She stated that "[the standards] cover each grade but you have flexibility to create what you want." She assembled the main topics and paced them out, so they fit within the school calendar. Once this had been established, she broke down each topic, always considering what is going to make the lesson engaging for the students. At the start of the year, she surveyed parents and students about their backgrounds. She used this information to revise her pacing calendar and tried to tailor assignments to student interests and diverse family background.

For developing most of her newer lessons, which always encompassed aspects of STEAM, she has a specific process similar to the one she used to develop ideas for movie sets. First, she goes to her favorite cafe, the cafe inside the New Museum, with books on the topic, a paper to write on, and a cup of tea. She speculated that she did her "best work there perhaps because it is quiet, but it is also so romantic and reminds [her] of Europe," where she is originally from. "When I got the idea...when I have a very clear mind...totally empty mind, visually I see the idea and I have to write [it] straight away or make a sketch so I remember." Once she got the idea, she goes back home and starts to work on it or does so during her planning periods at work.

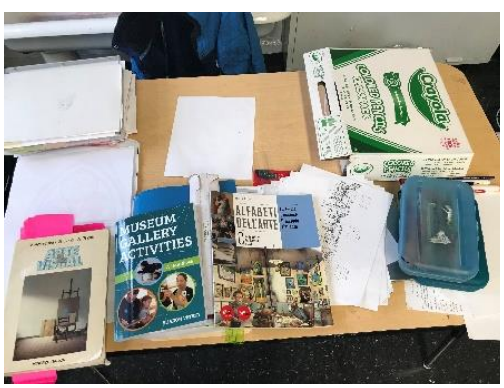
Sometimes her ideas for lessons require collaboration with other teachers. She usually connects with them via email or sometimes just casually drops by their classroom. She makes time to talk with other teachers about what they are doing in their teaching. If there is a subject she can expand upon, she makes every effort to do so. For example, when Isabella learned that the sixth-grade students were studying Shakespeare in their English class, she decided to create an extension lesson within her class where they would examine the various types of Shakespeare costuming used during that time.

On another occasion, Isabella shared during her interview and planning observation, to plan for a mini unit on botany, she had a brief conversation and an email exchange with the seventh grade science teacher, Luna, about plants so that she could create an activity where students create botany field guides. Luna took a few minutes to give Isabella an overview and shared her formal lecture and lesson plans with Isabella. In addition, Luna recommended several resources on the topic to further help educate the art teacher about botany. By combining her knowledge with that of Luna, Isabella created a lesson that integrates both disciplines. It would not be possible to have a field guide with sketches of the plants without understanding the crucial parts of a plant and illuminating them through illustration. If any of her discussions required more time, she scheduled a meeting or tried to connect with teachers she was working with via phone.

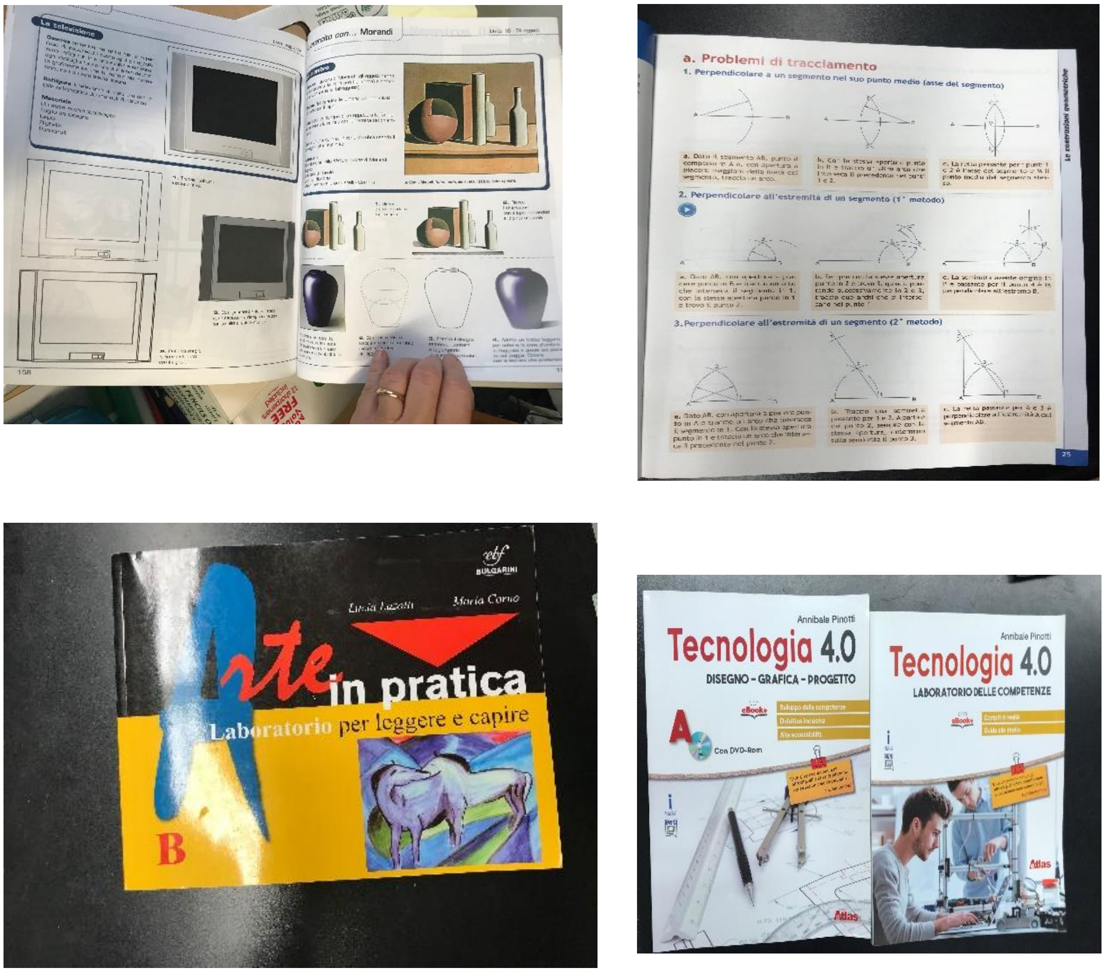
Isabella's workspace and classroom are filled with various types of books (art references, digital art, American art textbooks, Italian art textbooks (Figure 4.6).

Figure 4.6

Isabella's Workspace and Reference Collection for Creating STEAM



N*ote.* When Isabella is working on lessons at school, this is the main table she uses to plan out and organize her work.



Note. Standard art curriculum textbooks from Italy provide a more divergent approach to art instruction. Students' study and examine art as it relates to their everyday experiences and to their other classes. In the top left sample, one would learn about sketching everyday objects which can ultimately be used to design physical objects. In the top right, one there is an entire geometry section in one of the curriculums.

She also keeps student work and portfolios that she has created on hand as references when designing lessons. During the observations and in the interview, she continuously used and referenced her Italian textbook the most. In contrast to the United States, Italy has standardized their art curricula and required teachers to use these manuals as reported by Isabella. When examining them, they provided a more divergent approach to discussing and teaching art. In learning about art topics, students learned about the history of how the art came to be, the technical aspects that allowed it to be created, and ways for students to experience and think about the art as the artists did. As is evident from examining her handouts and posters around the room, there is consistency in her teaching approach and in her use of Italian curricula references.

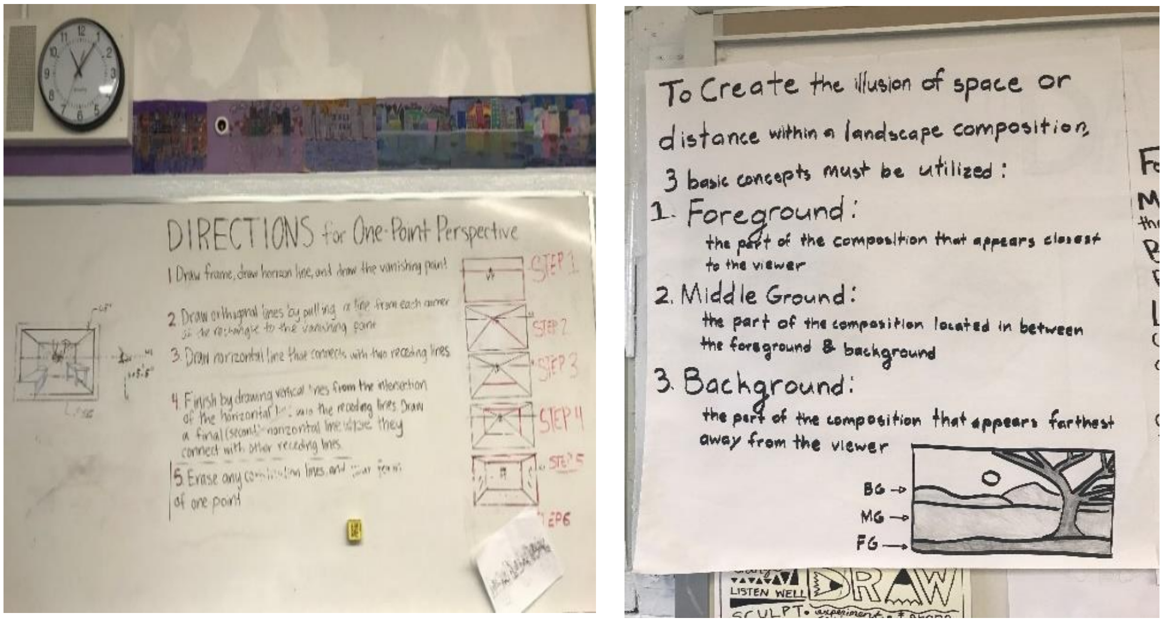
In addition to her use of books, Isabella participates in an abundance of professional developments offered by the Department of Education and various cultural institutions throughout New York. She uses knowledge gained from these events to incorporate into her classroom. Some of the past workshops have included using available technologies to create art, focusing on specific exhibits, and a look at various art techniques used by professional artists and how to bring them into the classroom. This will further be discussed in Isabella's revision section as this plays a major role in that part of her STEAM process. In other professional developments sponsored by various cultural institutions (i.e., the Metropolitan Museum of Art and the Whitney Museum), Isabella has been provided with art history development on new and not as well-known artists. She stated, "You do your own research, like a scientist would."

Implementing STEAM

As can be seen by her planning, Isabella implements her lessons by using a divergent approach. She uses her personal experience and movie set experience as a model for delivering instruction. She commented, "There is a portion of like going through research to create a final image. So, there is a creative process which includes all the artists… The idea to go from fantasy to reality." Walking into Isabella's classroom, it is apparent to visitors and students the content that makes up her teaching. She created customized hand drawn posters with the instructions and diagrams spread all over the room (Figure 4.7).

Figure 4.7

Classroom Guidance Posters on Prospective



Note. Instructional posters made by Isabella to guide students in their work and creation of STEAM products.

Note. Student work created from the Prospective lesson. Isabella had students do three different sketches of the same piece. They selected a landscape and drafted several versions, for example, one in black in white, one in a monotone, and one fully colored. The instructional posters in the classroom guided students in their work in making this prospective art.

Her handouts parallel these aids by having the information in multiple formats (e.g. visual pictures, physical models, written verbal guidance) which assists students who struggle. In presenting the material, Isabella models the real-life processes used and assisted the students in applying these techniques throughout lessons. For example, in a lesson where students were learning about perspective drawings, Isabella made posters and handouts that walked them through the steps of how to make these types of drawings (Figure 4.7). After going through the process, she allowed students to choose what landscape (i.e., they would want to draw and then had students apply the technique.

As discussed in how Isabella plans STEAM, she incorporates topics from other classes to engage and further teach students. This not only reinforced content that students were learning in other classes, but it also provided them a foundation to build off and go deeper into the content. It also provides a vehicle for students to demonstrate learning through another medium. For example, in one unit, Isabella had students making botanical field guides while they were simultaneously studying the topics of anatomy and physiology of plants in their biology class. Students looked at the works of various botanical artists (i.e., Georgia O'Keefe), the artists' process, and then used it to create their own field guide. By presenting the material through another lens, Isabella was able engage students who typically struggled when classes were taught in silo. Isabelle commented on the products students made: "This student's work is so beautiful. According to his science teacher he does not do well, and she was surprised to see the level of detail in his work." When showing another student's work, she said, "This student has special education accommodations and is in the self-contained class. Look at this work. It's so lovely and she put so much care into it."

The organization of Isabella's classroom seating also contributes to the implementation of STEAM. The work environment she fosters allows for collaboration. While students do individual projects, she has them strategically seated in groups and include activities that allow them to share and provide feedback to each other. The chairs are arranged so that they can collaboratively work, share, and provide commentary about their tablemates' work.

It was noteworthy, however, that sometimes the collaboration extended beyond the activity and could hinder students from obtaining information. During the various implementation observations in both phases that I attended, there were times when Isabella would attempt to lecture and share information, but the students would not be engaged. For example, when she was introducing the prospective unit, one student decided to pull out his computer and check his email. Two other students were having their own conversation and when she asked them to re-engage in conversation with her, they looked over for a few seconds and picked up where they left off in their personal conversations. By not paying attention, the students were unable to complete the activity.

When attending Isabella's implementation observations (both in the first and second phase), the lesson preparation and presentation were consistently well thought out and very detailed. Based on observations and reports from Isabella during interviews, students seem to be enjoying the lessons and are proud of their work. They can draw connections and transfer their learning to and from other STEAM classes and use them in new situations. During a field trip with the class to the Cathedral of St. John the Divine, I observed the students sharing information with the docent about the various types of columns and arches that they had learned about in Isabella's class. I wrote a comment heard from one student, "The column is Romanesque because in art we learned that they are round and more ornate whereas Gothic columns are pointed and more plain."

Revising STEAM

Once lessons are completed, Isabella reflects on them and evaluates how her students did based on rubrics she created. She also compares their work to a pre-assessment she administers at the beginning of the year. When she notices patterns of students not achieving the goals set out by the lesson(s), she tries to address it immediately. Once the correction is made, she takes the time to re-examine and identify where she could have been clearer in her instruction. Some past changes she has made to help clarify instruction and ultimately reach the goals of the class include adding diagrams with the instructions, providing samples, giving time to students in class to complete the work, and talking with other teachers about what the students have or have not already learned.

A major influence on Isabella revising her lessons is past participation in professional development. She states that “as you go to professional development, you get ideas to revise lessons already created.” As she has learned about newer technology tools available for students, she integrates them into her lessons; as a result, students can now have another medium to work with and further break the boundaries of classes being seen as strictly one subject classes. Other ways she has used technology to expand her STEAM curriculum include digital storytelling (a collaboration of English and Art), coding (a combination of technology to produce art), and video production (students go through the steps, including making storyboards, to mimic and master how real life producers do this for the big screen). The use of new format has also allowed the students to share their work with family and friends around the world.

Katherine: The Special Education Science Teacher

Katherine is a special education science teacher who has been teaching for 12 years. During this time, she has also taught mathematics and English Language arts. She is an advisor to the 6th grade students and is the emeritus chair of the Special Education Department at the school. During the majority of her time as a teacher, she was also a lead instructor for Urban Advantage, a partnership program with New York City's cultural institutions and the Department of Education that offers science professional development and support to public middle school science teachers. In this position she developed curriculum at the New York Botanical Gardens and taught teachers how to use it in their classrooms and connect it to a field trip at the New York Botanical Gardens.

Prior to her career in education, she had other experiences which influenced her ability to create and practice STEAM. In her previous career she was a development officer in charge of fundraising projects for non-profit organizations. She was also the Parent Teacher Association President. She described how she saw connections to education:

> I saw the role that the dramatic arts played in children's learning. Each year all of the classes in the elementary school would put on a play about a particular content matter. The students designed sets, sang songs, and acted in plays that taught science ideas or historical events. I saw the engagement that children had and how it deepened their thinking on the subject. (Katherine Interview, December 2019)

In Katherine's undergraduate institution, she was also an art history minor. Katherine has formerly been doing STEAM for eight out of her 12 years of teaching and defines STEAM education as the:

> Integration of math, science, engineering, art and technology; it is not teaching these courses side by side, instead integrating them in a cohesive manner so that students can consider and study the same phenomenon with different lenses and express their learning

through different media. It is also an easy way to make something that is really abstract very concrete. (Katherine Interview, December 2019)

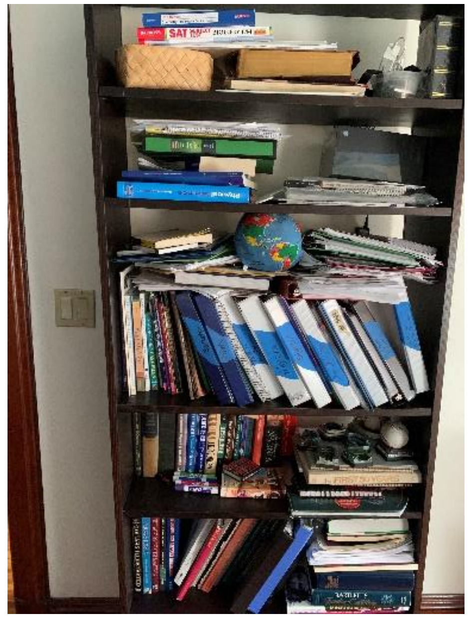
Creating STEAM

In creating STEAM, Katherine is a collaborative and backwards planner. She creates lessons with her general education science co-teacher and sometimes also plans with other teachers in various subjects. In past years, she also taught special education mathematics where she would consistently plan with the mathematics general education teacher. In planning with her co-teachers, her first step is to work with them and identify goals for the lesson(s). From there they devise a plan to reach those goals. Typically, they are dividing up the work and researching the topics they have been assigned.

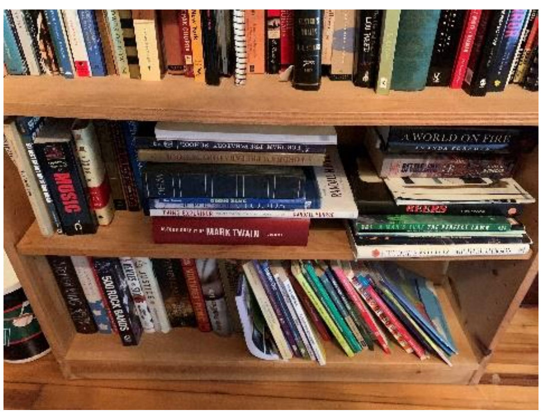
Katherine is an avid reader of books and the newspaper where she is always getting ideas. Her workspace is filled with textbooks and reference books from various levels and subject areas (Art, History, Mathematics, Engineering, English, Music, etc.) (Figure 4.8).

Figure 4.8

Katherine's Workspace and Reference Collection



Note. Katherine's workspace at home where she plans and creates STEAM lessons.



Note. Katherine's personal reference collection that she uses to create her STEAM lessons. Katherine is an avid reader of books and the newspaper where she is always getting ideas from. Her workspace is also filled with textbooks and reference books from various levels and subject areas (Art, History, Mathematics, Engineering, English, Music, etc.).

In addition to her personal reference collection, she keeps the various science standards nearby, like the Next Generation Science Standards and New York City Scope and Sequence (Appendix P). She is also familiar with the mathematics standards and sometimes pulls those out as well. Another resource heavily consulted during planning by both her and her science co-teacher are their master binders. In these binders they save all their past lessons in addition to student work. At the end of each lesson, they use post-it notes to reflect on their work so that the following year they will remember their thoughts and if any changes need to be made.

The student work is also crucial to the planning process. Katherine and her co-teachers identify any misconceptions students have, content the students obtained (or did not obtain) and help determine whether an assessment truly measured what students learned. It is noteworthy that they pick a diverse set of student work so that all types of students are represented for lesson planning. When Katherine has exhausted her resources mentioned, she sometimes consults other references including readings, Youtube videos, lectures, pictures, and artifacts to further deepen the goals of the lesson, especially when it is a newly created STEAM lesson.

Once everything is determined, Katherine records the agenda in a spiral notebook. This also serves as a reference for future years and planning. She also does personal reflections within the notebook and reports carrying it throughout the school day, recording any details that may have been needed during or after planning.

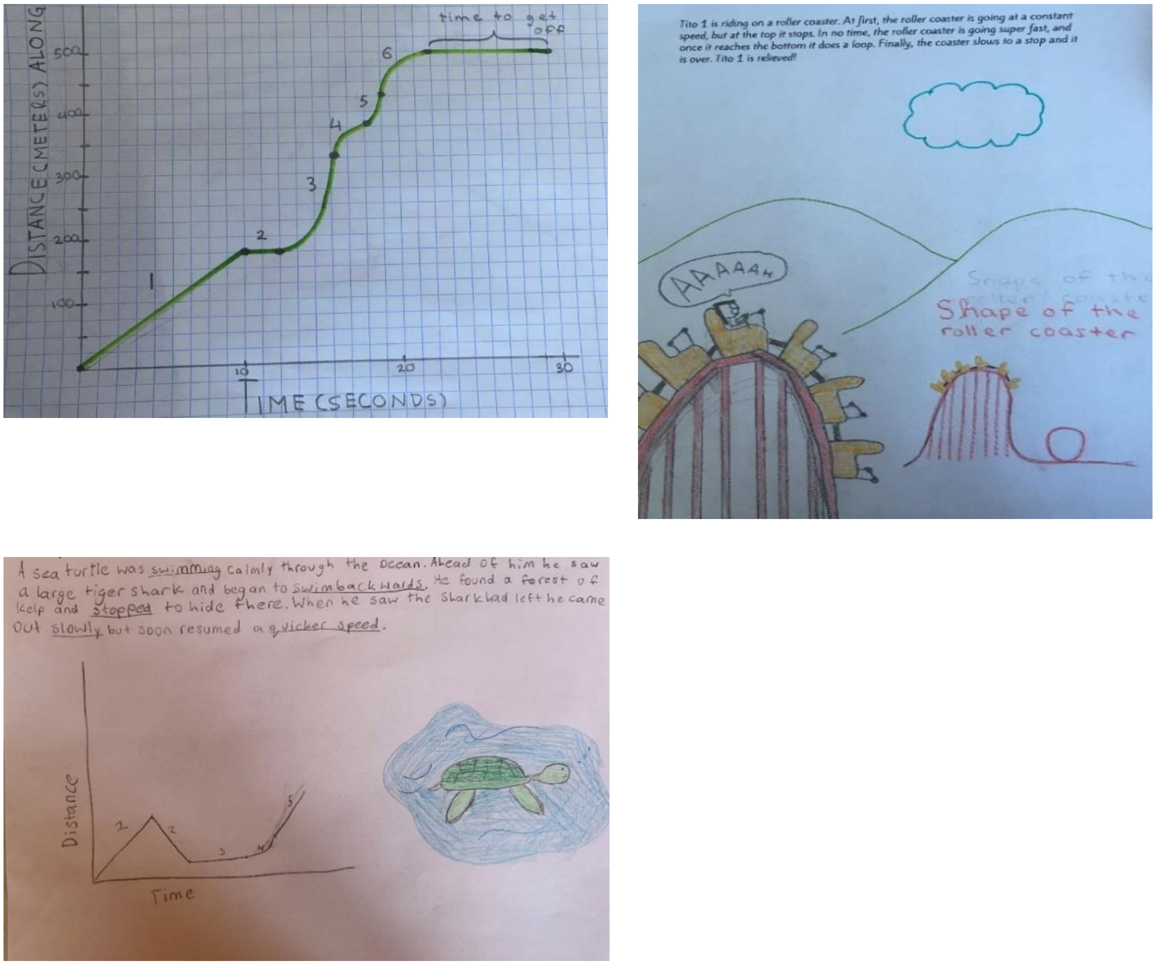
Lastly, in addition to the variety of resources used to create lessons, Katherine also participates in an abundance of professional developments offered by the Department of Education and various institutions throughout New York. At these events, Katherine learned ways to better differentiate instruction for her students. She learned to dive deeper into various content topics. She also attended professional development outside of the science and mathematics to see how to bring other subjects into her classroom teaching. In her interview and in analyzing her resources for classes, one can see components brought in from the professional development programs.

With all the resources Katherine has at her disposal, she is never without an idea. Sometimes, however, she gets caught up in the details causing her to deviate from her lesson goals, which makes it unclear whether the students fully ascertained the meaning of the lesson. Despite this challenge, students are still performing better than when the class was taught without the STEAM lesson as report by Katherine in her interview. Katherine shared that her "Motion Graph Story Lesson," which took several years to fully design, impacted students learning. She commented that her 6th grade lesson was foundational for students' learning later in science. The 7th grade science teacher told Katherine that she was able to eliminate teaching graphing from her curricula because the students came in with such a strong knowledge base for it and continuously referenced their 6th grade project.

In the STEAM Motion Graph Story Lesson (Appendix Q), students learned about the graphing and how they told the story of data. At the beginning of the series, Katherine introduced them to graphs that displayed motion (Distance vs. Time). They learned how to create a graph, but they struggled to understand the data they had plotted. After they construct the graphs, she would help the students "see" the motion changes by using real-life stories around the graphical data and what it was showing. By taking this STEAM approach, students were able to finally understand what their data was showing and explain what the data meant. In the culmination project, students created their own graph stories (Figure 4.9). This STEAM approach ultimately helped the students take an abstract concept and make it understandable.

Figure 4.9

Motion Graph Story Student Samples



Implementing STEAM

Katherine implements her lessons by engaging students through personal and real-life experience. As demonstrated in the "Motion Graph Story" lesson, Katherine teaches content by making it relatable to her students' lives. In the student samples presented previously, the scenarios for which the students made graph stories were from personal experiences that could be represented by data (i.e., riding a roller coaster, riding in car, walking to and from a location) or had been a plausible situation scenario (i.e., a turtle walking, a ballerina dancing).

These Motion Graph Story lessons simultaneously taught and reinforced other subjects, as well as engaging the students. In the students' mathematics and engineering classes, students learned how to construct and, to an extent, interpret graphical data. Katherine, however, had students engage deeper with the content in teaching them how to better interpret and explain the data through the art of storytelling. In the culmination project where they devised their own motion graph story, they constructed fictitious data by angling the slope and direction of the lines to match. This exercise forced them to understand the significance of slope and line direction. In the end, Katherine, who for several years taught with Justin (mathematics), noticed a significant difference in student understanding in both mathematics and science once this interdisciplinary lesson had been incorporated into the curriculum. She reported in her interview, that not only were the quality of graphs better in both mathematics and science but also that lab analysis sections garnered better scores for the detail provided. Students not only receive instruction on topics traditionally covered in science but also experienced an infusion of STEAM subjects. Sometimes science class is a combination of science and one other STEAM subject while other times it is a combination of all subjects represented in STEAM. In both scenarios, students are being taught to understand how science fits within the context of other areas.

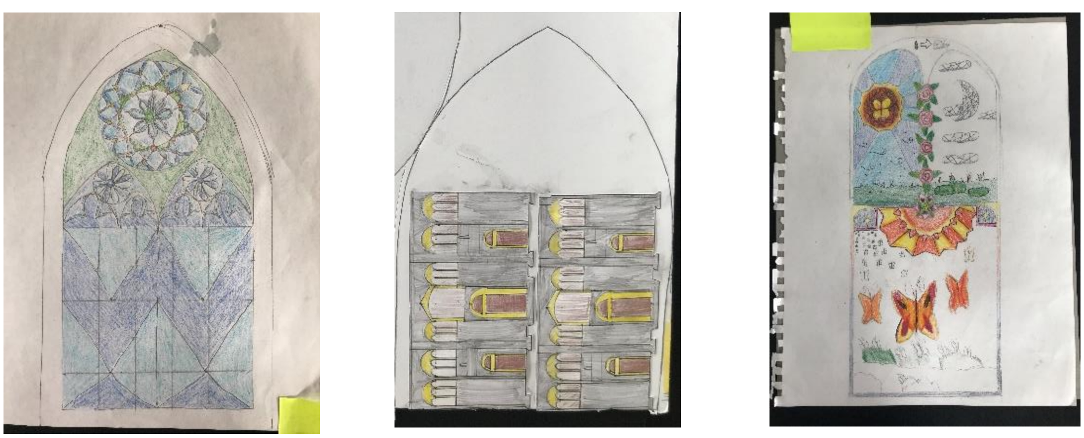
Katherine also engages students, especially those who are typically absent from STEAM (e.g., special education students, Black and Hispanic students), by making cultural connections with the content she is presenting. For example, during one of Katherine's lessons, students had the opportunity to find a piece of art and identify energy transfers in the piece of art. Katherine provided books from an array of artists. Several students noted (and seemed excited by) the fact that there were artists who had cultural backgrounds like theirs and even looked like them.

Another instance occurred in a joint field trip she plans with Isabella, the art teacher, and David, the Engineering teacher, to the Cathedral of St. John the Divine, a cultural institution in the community. This field trip demonstrates to students the combination of the three subjects to create this institution. The science of waves allows for light and sound to travel, the flying buttresses and columns allow the structure to stand tall, and the aesthetics used to decorate the building is a symbol of unity among different cultures and religions. Figure 4.10.

Figure 4.10

St. John the Divine STEAM Lesson with Science, Engineering, and Art Class

Note. The construction of a cathedral models inspired by the field trip to St. John the Divine and what students learned in their Science, Engineering, and Art classes. Students sketched out the façade and then constructed 3D models both in art and Engineering.





Note. Students also created stained glass windows based on how light reflects through different mediums, in this case glass. They also made designs based on their study of color in art.

In Katherine's interview, she also noted the many times she was able to engage special education students. On moment that she was incredibly proud of was when she was teaching the students how to make origami. Initially the students in her self-contained class were reluctant and intimidated by all the steps they would have to through but by the end of the class, one of the students (who was typically reserved during lessons) had taken the lead in instructing her classmates and the adults in the room. This was incredibly powerful as this demonstrated that the student was capable of learning when provided the right opportunity.

Katherine captures the attention and interest of students through real-life relations as well. In science, students studied sound waves and connected sound waves to sound waves in a concert hall. They learned about the Walt Disney Concert Hall and Frank Gehry's process of constructing this landmark. Katherine then presented them with a similar prompt and asked them to design and engineer a model of their ideal concert hall. Like architects, who are the ideal model of STEAM in practice, the students had to create a building that was aesthetically pleasing but also functional. This involved researching a plethora of other performance spaces to determine what features would be ideal for theirs. They also had to formulate a proposal considering the audience, resources, and budget--just like professional architects. In addition, students needed to think critically about obstacles that both current performance spaces faced and in their own models. By doing so, they could make logical and informed decisions to come up with the best product. Students were engaged at every level and had the opportunity to demonstrate their learning in various ways. Because the assignment had multiple levels, it allowed all types of learners to demonstrate the knowledge they had gained in ways they felt they would be the most successful. Some students who were more kinesthetic focused constructed a model whereas other students who were more visual constructed floor plans (Figure 4.11).

Figure 4.11

Concert Hall Construction

Note. Concert Hall Sample 1: The tin foil was installed to help with the sound project. This was also created to be a small theater to help the sound vibrate.

Note. Description of the Concert Hall Sample 2 written by the student who created the concert hall as shared by Katherine, the science teacher.

I designed my concert hall to this formula- “RT60 = 0.16 V / a S where V is the volume of the room, S is the total surface area and “a” the absorption coefficient. When all other quantities are in standard metric units, the reverberation time RT60 is given in seconds.” The absorption is the open window. (That’s why I included it). Following this formula reduces the amount of reverberation in the room. At the Fogg lecture hall at Harvard, the reverberation was so bad that people couldn't hear anything.

My concert halls ceiling height changes- The source of the music has the lowest ceiling height and then increases the farther out it goes. I made the ceiling this way because sound waves travel similarly. Because the ceiling has that shape, it gets the most out of the sound- therefore hearing it better.

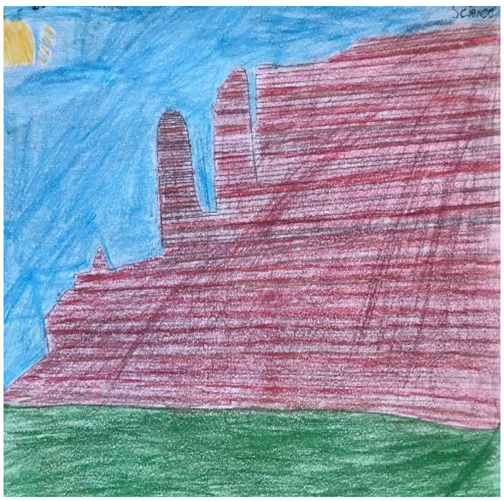
I made my concert hall out of popsicle sticks and paper mâché. The popsicle sticks act as wood and the mâché acts as plaster. According to the sound zipper (linked below), "Wood can truly enhance the visual beauty of a concert hall, and proper use can improve concert hall acoustics." However, if the wood paneling is too thin, there is air and space behind it which will ashore low frequencies. Because of that, people put and design plaster behind the wood to fill up the space. I made the structure of my concert hall out of paper mâché (the plaster) and covered it in popsicle sticks to ascots as wood paneling. Although putting the popsicle sticks on the outside doesn't do anything, let's pretend they're on the inside because I couldn't put them on the inside just because of the shape.

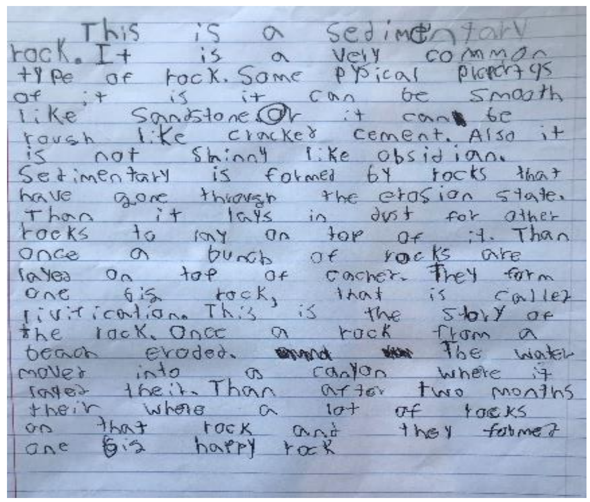
In teaching STEAM, Katherine also engages students through modeling. With this teaching approach she provides examples of what she generally expects, so that there is room for creativity and not just copying of the expected product, from the students. This visual representation guides the students in their work. In addition, she utilizes many hands-on visual activities that reach various types of learners. She also uses modeling to replicate how professionals utilize STEAM to be successful in their fields.

For example, one of the lessons that I observed occurred at the Hall of Planet Earth (Appendix R) at the Natural History Museum. Katherine had students put themselves in the shoes of artists hired by the museum to create a display around the information being presented (Figure 4.12). As artists, they also need to be transformed into scientists and become researchers to create a display that will not only be aesthetically appealing and accurate but also contain information that will educate the visitors coming to the museums.

Figure 4.12

Planet Earth Mural Exhibition





This is a Sedimentary
rock. It is a very common
type of rock. Some typical propertys
of it is it can be smooth
like Sandstone. Or it can be
rough like cracked cement. Also it
is not Shinny like obsidian.
Sedimentary is formed by rocks that
have gone through the erosion state.
Than it lays in dust for other
rocks to lay on top of it. Than
once a bunch of rocks are
layed on top of eachother. They form
one big rock, that is called
lithification. This is the story of
the rock. Once a rock from a
beach eroded. The water
moved into a canyon where it
sated their. Than after two months
their where a lot of rocks
on that rock and they formed
one big happy rock

Note. Planet Earth Mural Exhibit Design Student Sample

Revising STEAM

Katherine is continuously revising her lessons year to year. After every lesson, she formally records how the lesson went and notes any changes that should be made and/or parts that worked really well. She simultaneously does this with her one science co-teacher who makes notations on the handouts provided and lesson plans using post it notes. All these resources are stored in the middle school 6th grade science binder and get revised the following year.

Both Katherine and her science co-teacher also partake in a lot of professional development throughout the year. At these events, they are always considering what lessons they currently have and how they can supplement or revise with information and activities provided by these sessions. For example, when they initially introduced the concept of energy, they had the students read an article and annotate at the students' discretion. They attended a several workshops sponsored by Urban Advantage (a middle school professional development provider in collaboration with the Department of Education and various cultural institutes throughout the city). The program they attended focused on reading and literacy in science education and taught them how to assess students more fairly in various ways. Instead of just looking at annotations, which is challenging for students with reading and writing disabilities, they provided activities where students could demonstrate their learning through drawings and captioning of pictures.

Lastly, Katherine and her science co-teacher always deconstruct their lessons post-delivery. Using a diverse sample of student work (representing high performing, medium performing, low performing, special education, and racially diverse students) they evaluate how students did and look for patterns that would suggest the students acquiring or not acquiring the content. They also examine whether there are trends from past years and from when they taught science in silo as compared to now. The deconstruction also allows all teachers to offer new ideas that could move lessons forward for the future and sometimes even sparks new lessons within the year and throughout other subjects that build on what the students have learned from the initial lesson.

Teacher Profiles Summary

The STEAM teachers presented in this chapter create, implement, evaluate, and revise STEAM in their own unique way. Their diverse backgrounds provide them with experience that allows them to create colorful lessons that significantly impact student learning. Their approaches to the STEAM process may differ; however, there are certain themes that are consistently common among how these teachers execute STEAM: collaborating with others, continued learning within and outside their field through professional development, the use of prior experience to develop lessons, the use of a variety of resources to create lessons, the engagement of students through personal and cultural connections to content, and incorporating lessons with multiple modalities that demonstrate various types of learning. The STEAM teachers have shown that through their STEAM curricula students are able to better engage with content which ultimately leads to them to the construction of their own knowledge that can lead to gain knowledge across various subjects and use the information to make impactful decisions for their future lives and careers.

The next section demonstrates how teachers worked together as a community of practice to garner new ideas around the STEAM process. Together they reflected on their individual experiences, revised how they implemented STEAM in their classrooms, and worked together to devise new curricula that allowed their shared students to learn content from a multitude of different angles. This not only reinforced learning between subjects but also allowed students the opportunity to make connections between each disciple. Both meetings with the STEAM teachers captured in the next section were scheduled to be a focus group where teachers could learn about each other's practice through a series of questions (Appendix K). They deviated from this task but provided spaces where STEAM curriculum continued to grow and evidence that this approach to learning is worth the investment.

Focus Groups Turned Planning Sessions

For the past few years, these STEAM teachers along with other colleagues, have been moving towards creating a more interdisciplinary curriculum. When this endeavor started, the team would just plan one joint unit together in June. The faculty would select a common theme and then present content from the perspective of their individual subject area. Early in this endeavor, teachers selected the content on their own around the theme and did not consult each other. In 2018, the STEAM team decided to add more interdisciplinary lessons dispersed throughout the school year. This year, 2020, the STEAM team, as partially guided by this study, prepared for, and implemented their most cohesive and ever fully collaborative (with all STEAM teachers working together) STEAM curricula to date. In these occurrences, the STEAM team created, implemented, evaluated, and revised the unit curriculum together.

Focus Group 1 Turned Planning Session: A Collaborative STEAM Unit Around St. John the Divine Cathedral, a Community Institution

After interviewing the teachers in the study and observing how the participants planned their classes in the fall semester, all the teachers came together in a focus group to share their STEAM experiences; they defined what STEAM was and how they generally planned for it. They also shared a few examples of STEAM lessons they had done throughout their careers as STEAM educators. As the conversations continued, teachers seemed to identify where in other curricula they had made ties or could make stronger ties to their content area. For example, Justin started brainstorming ideas about how he could incorporate music into his mathematics lessons based on the sound lab that Katherine, the science teacher, had created.

> One idea……take trigonometry to where maybe we have some oscilloscopes and we're really looking at like the waveforms of different sounds in different pitches and using sound to illustrate and deepen the understanding of the sign function, for example, or like just trig in general. (Justin in Focus Group 1, January 2020)

Several teachers also noted challenges they had with creating STEAM while others shared how they were able to conquer challenges and limitations they faced. Initially coordinating schedules was a challenge. Most teachers at the school teach across grades which makes it difficult to find common planning time. To resolve this problem, the teachers that could meet, for example, Katherine (science) and Isabella (art), had a brief meeting to discuss their goals for the overall lesson. They exchanged lesson plans prior to the meeting which allowed them to understand each other's goals. When the meeting occurred, they devised a plan that allowed them to coordinate and collaborate on their goals. They also produced a joint plan which they were able to later share with other teachers at a scheduled grade team meeting. Katherine and Isabella shared with me that they would be bringing their plan to the rest of the STEAM team this during one of their observation planning sessions and I decided to schedule my focus group within the same time frame and exchange out the scenario question "How would you design a lesson(s) around the following scenario for your STEAM classroom" with this authentic lesson actually taking place. By requesting a few minutes during an already scheduled meeting, they could plant the seed of their idea with the other teachers.

The final segment of the STEAM focus group was Isabella (art) and Katherine (science) sharing a lesson they had jointly planned for the upcoming field trip to St. John the Divine Cathedral. Originally, I had planned to give all the STEAM teachers a fictitious scenario to analyze and re-plan together, however, since there was already a partially assembled plan already and these teachers were soliciting feedback, I choose to substitute the original plan and instead use this to observe and partially guide the teachers.

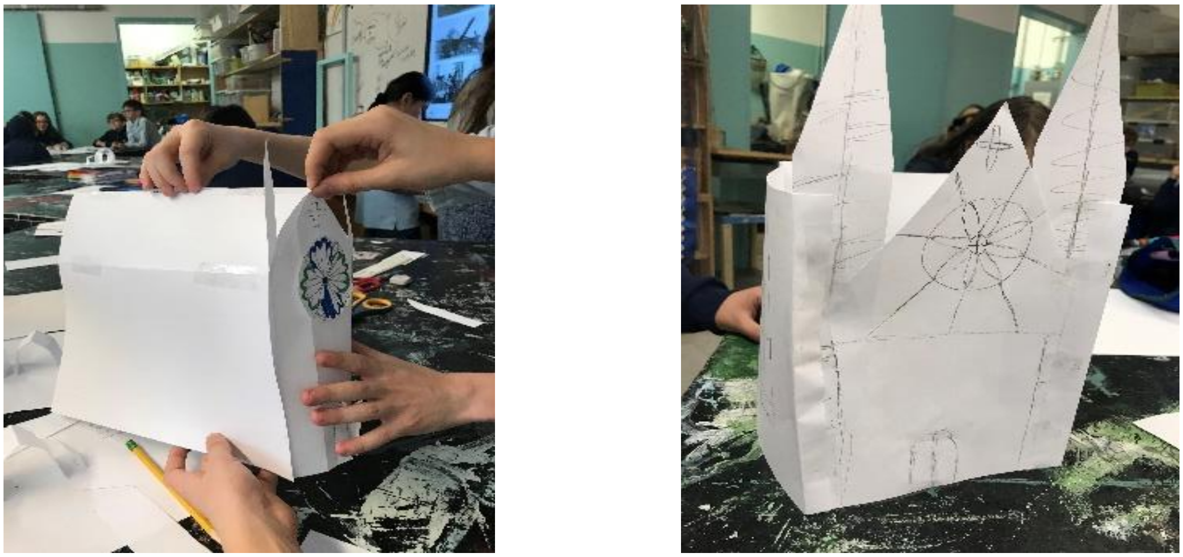
Katherine and Isabella shared their process and the expectations they had for this field trip. They brought the lesson plans (Appendix S) and the handouts that would be distributed to the students (Figure 4.6). Throughout and after the presentation, the teachers solicited feedback from their colleagues. The engineering teacher (David) started orally brainstorming ideas he had to supplement the trip and build off what the science and art teachers were doing. He excitedly decided that he wanted to participate in planning the unit and preliminarily shared his lesson plans. David excitedly shared that he was going to show a video on the Chartres Cathedral in France. He would show the video prior to the trip and then discuss it with the students. His preliminary plan was to help them find elements that could be seen in both St. John the Divine and Chartres Cathedral. While David, who was unable to make it to the common planning time, joined Isabella and Katherine at this later stage. He never formally met with the art and science teacher in person, but he corresponded with them via email, and together they asynchronously planned. Justin, the mathematics teacher was also very interested and would asynchronously email preliminary plans and ideas he had to make geometric connections with the stained glass and architecture in the cathedrals to a later STEAM project in the spring. Unfortunately, due to the COVID-19 pandemic, Justin did not get to add his additions, but the teachers did all decide that when school would return to normal post COVID-19, they would be sure to incorporate those lessons and plans.

Contrastingly, the English teacher (John), who is not part of the STEAM team, stated that he was not quite sure how he could bring his content area into the theme of the trip. The art teacher (Isabella) jumped in and shared how the stained-glass windows were created to tell stories as not everyone was able to read but still needed to be educated on various topics. For example, most cathedrals have biblical depictions whereas St. John the Divine is more modern and has several non-religious windows.

Post the planning session, Katherine, David, and Isabella eventually came up with a series of lessons that helped prepare students prior to visiting the Cathedral and to help them further process what they had learned after the visit. Engineering examined the structure of the cathedral, art examined the aesthetics of the building, and science had students study the wave motion of both sound and light Figure 4.13.

Figure 4.13

Collaboration unit on Cathedrals with Art, Engineering, and Science



Note. Models of the cathedral constructed out of paper in Engineering class.

Note. Italian Art book used to create unit lessons for the cathedral unit. Handouts were made from this resource to help guide student learning during the field trip.

The development of this interdisciplinary curriculum has taken about three years. Isabella and Katherine for the past two years would briefly discuss and modify lessons based on conversations and resources shared between each other; however, this past winter, January 2020, is when they finally started collaborating from the beginning by sitting down and planning out the unit together. It was also the first year they had incorporated other teachers to participate. Because of the time and energy that went into designing these STEAM lessons, students came away with a deeper understanding of content and context as compared to when taught in silo.

For example, as mentioned previously, David had students build models of the Cathedral. One of his pupils, a special education student who typically does not participate, constructed a paper model incorporating aspects learned in art, science, and new information garnered during the field trip. Addition, during the field trip, it was interesting that one of the students immediately commented on one of the stained-glass windows that had a figure whose skin tone was dark, like hers. She engaged with the tour guide and continuously pointed it out. Typically, she is quiet during class. In a post filed trip lesson in Isabella’s class, the student designed a stained glass window in the style of the one she saw on the trip.

Focus Group 2: Discovering New Ways to STEAM together through the 6th Grade COVID Chronicles STEAM Project

During the spring semester, I observed teachers again in their planning and implementation of STEAM lessons. Once the observations were completed, the teachers came together again for a post-implementation focus group turned planning session. The teachers met to not only discuss changes they made in creating, implementing, and revising STEAM lessons with their colleagues but to also deconstruct a grade-wide STEAM project that emerged in the second semester called “COVID Chronicles.”

At the beginning of the focus group, I re-asked teachers in the group to share their experience defining, creating, implementing, evaluating, and revising STEAM. The teachers’ definitions had remained the same, however, several of the teachers had recognized a shift in themselves and how they created, implemented, evaluated, and revised their own STEAM curriculum. One notable change came from David, the Engineering teacher. David reported that "I talk to other teachers because of you. I find out what they are doing and specifically ask them for the topics they are covering. Then, I look at my own lessons and see how I can connect what they're doing at the current time to what I'm doing." During the second semester, I did not formerly see this outreach, however, when he was showing me projects, like his Arduino piano, he referenced Katherine's wave project where she taught students about musical instruments.

Since the first focus group, Katherine (Science) was inspired to also work more closely with her colleagues. Recognizing that time and space was a challenge, as it repeatedly came up in the first focus group/planning session, I worked with Katherine throughout the second phase to find a professional development opportunity that helped to overcome these barriers. We found a program at the Metropolitan Museum of Art (MET) that custom designed programs for groups of teachers around the exhibits at the museum. Using one of the teachers' longer professional development days, where the teachers were scheduled to be present and working anyway, she scheduled the customized professional development workshop at the museum. To prepare for this, Katherine, throughout the second phase of the study, talked with each teacher and worked with both the docent at the museum and me to narrow exhibits that could be used for the professional development and ultimately a field trip to show students how the combination of all these areas led to the development and success of these societies.

During the focus group, the teachers heavily discussed the collaborative planning that grew out of this experience. They agreed that it helped each other trust one another more and gave everyone an equal starting point to work on a joint project. They talked about how they felt overall successful with projects like the St. John Divine STEAM curriculum but discussed how sometimes it was tricky to plan together because teachers were coming into the planning at different points. With the MET professional development, they felt that having a common starting point allowed for more equal buy in to developing a project and more trust in reaching out to each other. For example, David (engineering) and Justin (mathematics) shared during the focus group how much they enjoyed talking about the geometry of the Alhambra in the Middle Eastern Section of the museum. David further discussed the plan him and Justin had started devising throughout the second phase of my research collection on how Justin would introduce the various geometrical shapes and how he would build on it to explain the architecture of this monumental structure. David was also vocal about ideas he had brainstormed since the visit around both sixth-grade curricula and other grades he taught. He shared that he was able to relate the new information learned at the professional development to what he already does. He also thought about longitudinal learning and how he could create lessons on these exhibits that built on top of each other from year to year, especially since he is one of the few teachers who has students throughout all of middle school.

Throughout the conversation, teachers also referenced the various times they had planned in the grade team meetings post the excursion. Unfortunately, due to COVID-19 this project did not get implemented as the museum and school both shut down, but the teachers agreed during the focus group that once the city returns back to normal, they would be back to working on this project. Lastly, at the focus group the teachers and I learned that Isabella, the art teacher, had begun making contacts with other institutions for more STEAM team experiences and educational opportunities to ultimately benefit their students. The teachers were all very excited and were already thinking about other professional developments either created by institutions or developing one themselves for the entire team.

Once the first part of the focus group was completed, I used the remaining time to discuss COVID Chronicles, a new STEAM project developed by the teachers (instead of the original final question I had planned which was to ask them to analyze a scenario for the STEAM classroom). This project that they developed emerged in the second phase of my research when the COVID-19 pandemic interrupted in person learning and everyone was forced to teach and learn from home. While this was disappointing to students and teachers alike but was an opportunity for the STEAM team to come together and develop a new learning opportunity. Here is the description of the project as composed by the STEAM team:

> The COVID pandemic has resulted in unprecedented and sudden changes in how people live, work, and learn across the globe. As of this proposal, students in New York City have been especially affected because of the city's high rate of infection and transmission. Regardless of the future course of the outbreak, the period between February and June 2020 in New York City will be one of historic importance and great personal consequence for city residents.

This project aimed to help students describe and document how the unfolding pandemic impacts their lives personally and academically, as well as how it impacts the lives of the people closest to them. Students will create lasting documents in a variety of media that capture what it's like to learn, grow, and care for others during a time of disruption. The audience for these documents may be the student's future self and family, their peers, or the public.

This project was an archetype of how teachers create, implement, evaluate, and revise STEAM. From the beginning, all teachers were invested in the project, which represented both a need for the time and the coming together in creating and implementing STEAM.

Creation of STEAM

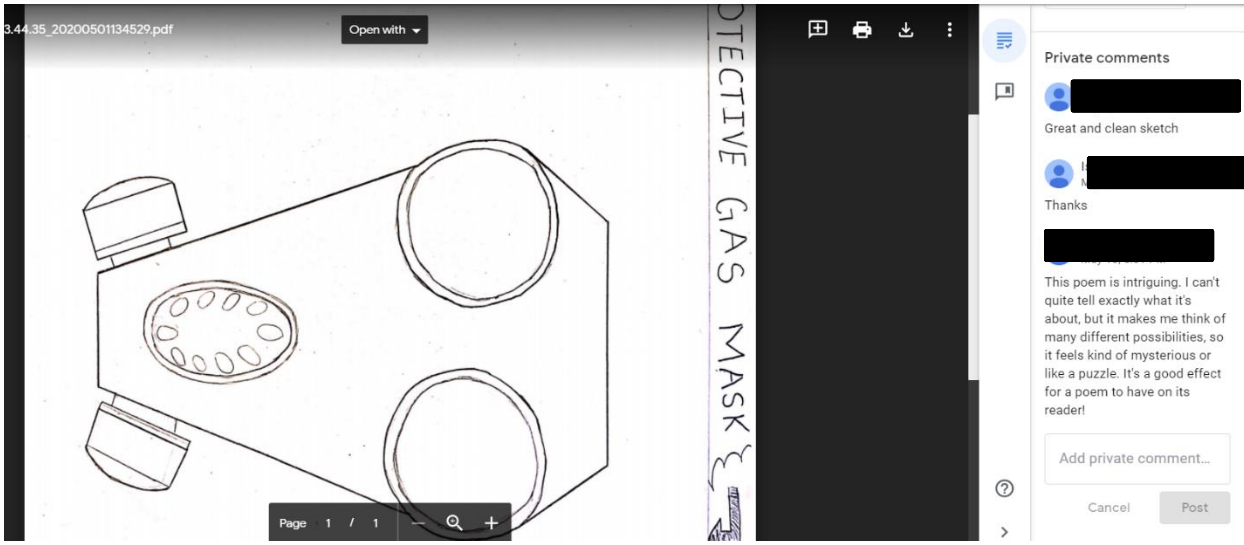
Justin (Mathematics), who first devised the project spent about one hour discussing the initial stages on the phone with the STEAM team Katherine (science), Isabella (art), David (engineering), and me (the researcher). As this team had worked so closely together in the past and had already had several successful lessons and experiences developed, he felt calling together these individuals to lead this project the best option—they also agreed when they had heard about it from Justin. They created a Google document where they worked together to create a proposal for the rest of the sixth-grade faculty to examine. The teachers split up the various sections, wrote them up, then revised each other's work. This process was done asynchronously. Teachers would put their ideas into a joint document and others would provide suggestions when it was convenient for them. They did this until a final meeting was determined and a proposal for the rest of the team was ready to present.

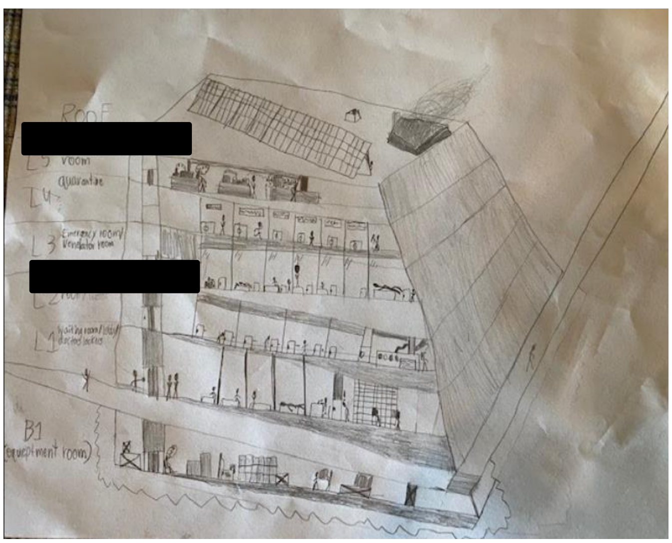
The teachers then called a meeting (which lasted 45 minutes) with the entire 6th grade faculty and the after-school staff to share the project proposal. They debated specifics, such as the structure, mini projects within the overall scope of the unit, their roles, the goals, and the expectations of the students. Ultimately, they all agreed and committed to this grade-wide STEAM unit called "COVID Chronicles," which was spearheaded by the five teachers who practice STEAM, and the five teachers who were participants in this study. They determined that it would be a weekly assignment every Friday where students would receive a menu of options from different subjects that they could choose what to do. All teachers, paraprofessionals, and staff assisted with making prompts to put into the master Google doc that everyone worked on during their own time (asynchronously). From there, teachers were given different tasks based upon their availability. Due to scheduling demands, some teachers taught across grades, and special education teachers had extra academic sessions. One teacher was designated to post the assignments every week and was responsible for sending reminders to the staff while others alternated working directly with the students for office hours.

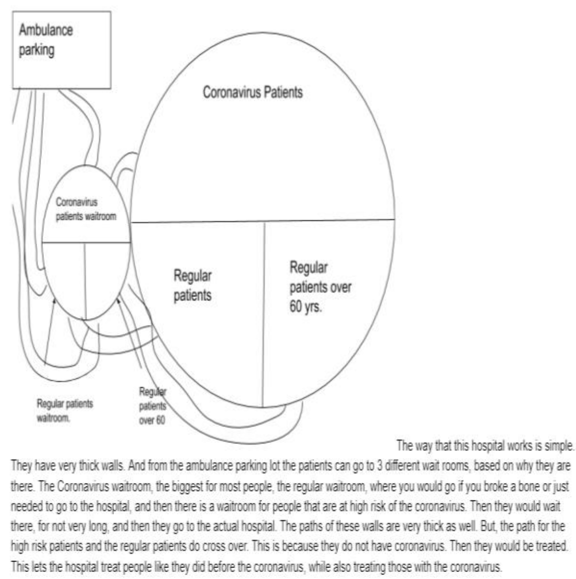
Every Friday, students were given a menu with various STEAM assignments that related to how the students were experiencing the COVID-19 pandemic. Some prompts helped them process what was happening while others had them apply their content knowledge from their classes to solve challenging problems individuals faced in the pandemic (Appendix T). The students would choose several prompts from the menu, complete them, and submit them via the COVID Chronicles Google Classroom, a shared online classroom with all faculty and students. Once the work was completed, students were divided up among teachers, paraprofessionals, and after school staff for work review. The faculty had one week to go through their assigned students and provide written feedback on the assignments the students did Figure 4.14.

Figure 4.14

COVID Chronicles Feedback







ate comments

[redacted]

Very interesting construction and view of the interiors!

[redacted]

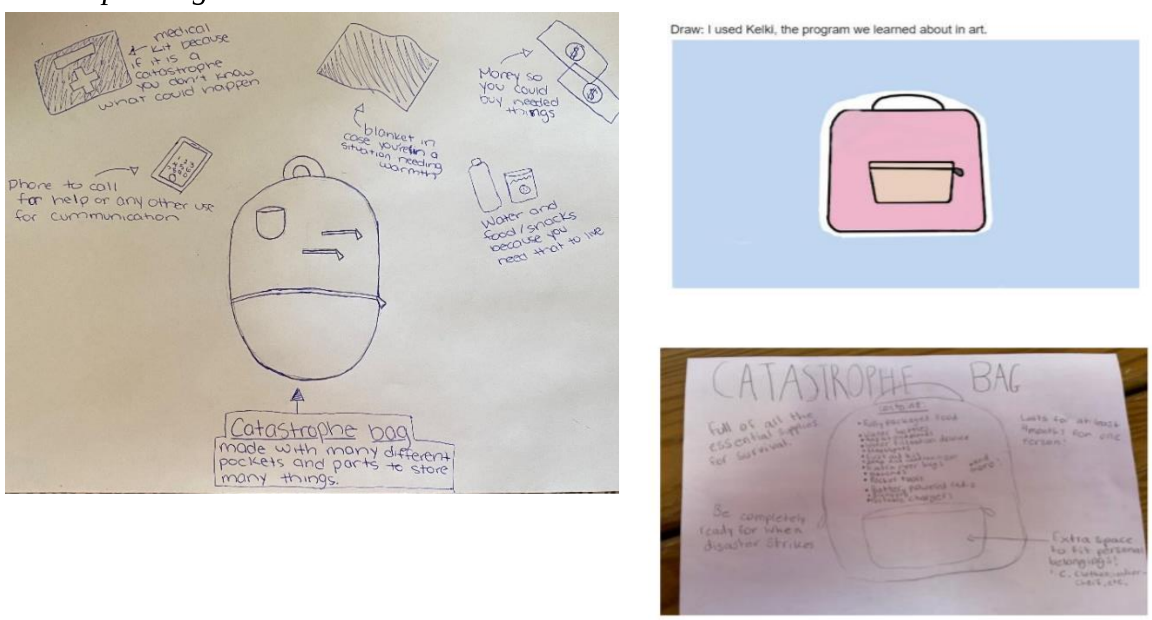
I think a lot of people can empathize with what you say about being afraid to go outside, but also wanting to at the same time. I definitely feel that way, too. It's not a good feeling and I'm looking forward to a day when we don't have to feel that way anymore.

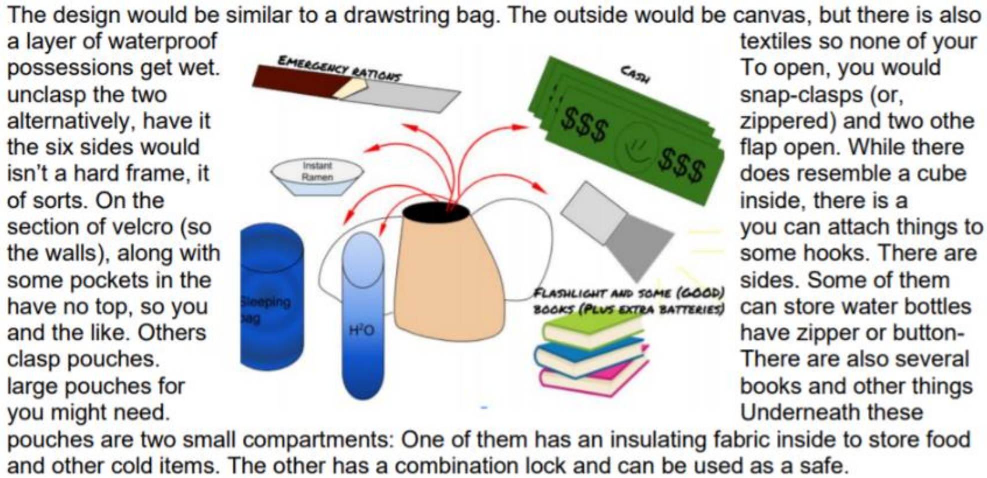
Note. Once activities were completed each week for the COVID Chronicles project, the sixth-grade faculty would provide written feedback on what students turned in. The entire grade was broken up among the sixth-grade faculty. The faculty used the comment features on Google Classroom to respond to students and their work. Every two-three weeks faculty rotated evaluating the students so that they were able to see the entire grade's work.

Each week, teachers would discuss and reflect on the progress on the COVID Chronicles mini lessons and determine what projects worked best under the challenging circumstances. For example, one of the initial projects was to make a catastrophe bag (Figure 4.15).

Figure 4.15

Catastrophe Bags




The design would be similar to a drawstring bag. The outside would be canvas, but there is also
a layer of waterproof textiles so none of your
possessions get wet. To open, you would
unclasp the two snap-clasps (or,
alternatively, have it zippered) and two othe
the six sides would flap open. While there
isn't a hard frame, it does resemble a cube
of sorts. On the inside, there is a
section of velcro (so you can attach things to
the walls), along with some hooks. There are
some pockets in the sides. Some of them
have no top, so you can store water bottles
and the like. Others have zipper or button-
clasp pouches. There are also several
large pouches for books and other things
you might need. Underneath these
pouches are two small compartments: One of them has an insulating fabric inside to store food
and other cold items. The other has a combination lock and can be used as a safe.

Note. Instructions from the COVID Chronicles Assignment: Make a Catastrophe bag. What would you put in it? Design what it would look like and diagram an advertisement to market your catastrophe bag. See New York Magazine Article

When it came to implementation, and based on the other mini projects, the teachers determined they could make it more tailored to the students. They decided to have students pick and either photograph or draw items in their homes that could be used rather than just telling them to think up objects. Further, they expanded the project by having students justify why they would need those objects. This check-in idea sharing, and reflection time allowed the lessons to be more tailored to the students impacting their learning more than if it was a generally devised lesson.

During the focus group 2 reflection discussion, one teacher pointed out that she had noticed that over time, much of the faculty had not only reviewed their assigned students' work but also the work of other students who were not assigned to those specific teachers. The faculty openly admitted that this indeed occurred and some even came out and said, in summary, that "they enjoyed and very much valued this project. I had so much to do and our schedules were so demanding, but I couldn't stop looking or putting them down." The faculty also discussed how they liked that some of their colleagues had participated in some of the prompts and that the faculty was able to also make a portfolio at the end. Justin and one of the English teachers commented that they "thought it was nice for the kids to see how we were going through this difficult time as well but that we were able to find ways to overcome it through this project."

The discussion also focused on the end of the project where students made a COVID Chronicles scrapbook compiling their best work of choice. The grade held a community day where the students could present their work virtually with their classmates and families. Justin commented "it was amazing to see this and what was more impressive was that we had to add more days. I think this speaks volumes to the success we had."

Another major point of discussion from this STEAM project was the engagement of Special Education Students. Many special education students also participated in the various mini lessons and the majority of them wanted to present to their classmates. Prior to these lessons, teachers reported that many special education students struggled to get their work done and would typically shy away from any type of presentation.

The team also discussed how everyone felt zoomed out by the end of the year, but, for a second it seemed the teachers and students did not care and that "the silver lining to COVID in general was that this project helped them to finally feel like a community again after having this horrible experience" (Katherine, focus group). The teachers discussed how they enjoyed listening to the students asking questions and sharing comments about the work being presented. They also discussed the distribution aspect of the overall project that since the product was made virtually, they could record the presentations and send them to family and friends who were not able to attend the presentations. They also became samples and models for the future as these projects were now historical documents that would live on longer than the class and could be viewed by future generations.

Overall, the faculty concluded that the students seemed very engaged, especially those who struggled with their general schoolwork. It appears giving them choice through different modalities (i.e., art, writing, etc.) allowed all learners a vehicle to participate. This resulted in approximately 80 percent of the students participating, which was a number far higher than pre-COVID. The faculty also commented on how it was a way for students to connect with others, especially in a challenging time where everyone was self-isolating for safety. It gave students a familiar routine, enabled collaboration, and supported students' reflection on what was important to them and what they were authentically experiencing. It also provided an avenue for families to be included.

Once the project concluded, the faculty came together to discuss the strengths and weaknesses. From a planning and implementation perspective, teachers appreciated that they could share teaching responsibilities and trade off various topics which gave them more time in their curricula to do other things. The asynchronous planning, which was a continuous working Google document, allowed faculty to plan on their own time, give feedback, and build on each other’s ideas. Teachers also found it was a good balance to rotate the groups of students so that they could see a wide variety and receive diverse feedback from an array of teachers.

Some challenges did arise throughout the project. First, 20 percent of students did not fully participate in the lessons. There was no firm plan to assist them nor was there a group or person designated to consistently follow up. A few faculty members struggled to keep up with the planning and were sometimes late with providing feedback to students. In addition, some faculty also needed to be prompted several times to provide information for their mini lesson. One technical aspect that was challenging was the shared Google classroom. Some teachers posted multiple lessons and created their own portals which was confusing for both the faculty member in charge of doing all the postings and for the students. Despite these challenges, overall, the project went well. The turnout for the 6th grade students, as stated before, was very high as compared to the turnout for other grades.

In this focus group, the faculty were ready to start revising for the following year and did some preliminary planning and thinking about how it could be revised and re-integrated. They preliminarily tackled some of the challenges they had faced and came up with some preliminary solutions. For example, for students who were not as participatory, figuring out where their interests were and making accommodations early on. For example, some of our struggling students excelled at one genre over others. We discussed letting them do the first several weeks just using that genre instead of trying to get them to do the mix of various prompts. They also discussed teaming up to create prompts that way there would always be two perspectives and more balance when outside work got challenging. Some other ideas included connecting the COVID Chronicles with mindset and new belonging. As the presentations were very successful the teachers thought that doing more interaction and sharing could help strengthen mindset and belonging. Students who typically did not talk in person class were very willing to share their presentations which gave them a new sense of belonging; therefore, encouraging and providing space for more of this.

The notion of story is central within research on creating, implementing, and revising STEAM. Throughout the combined use of various data sources, we have been given insight into teachers' knowledge and practice (Rosiek & Atkinson, 2007). These cases serve as models to help guide STEAM teacher practice for those currently doing STEAM and prospective STEAM educators.

Chapter V

DISCUSSION OF FINDINGS

In order to address the research questions, data was gathered and triangulated from various sources: individual semi-structured participant interviews, questionnaires, observations, focus groups with all participants, and artifacts and document collection. These data were analyzed in light of the research questions and in accordance with the theoretical frameworks presented in chapter two: Community of Practice, Constructionism, and Reflective Theory. Comments were coded and categorized according to indicators from these theoretical frameworks. Based on how all the teachers created, implemented, evaluated, and revised STEAM, various categories were created. For how teachers create STEAM, three categories were created: collaboration between colleagues, resources to create STEAM (professional development, references books, online resources, past experience, etc.), and student interest. For how teachers implement STEAM, two categories around engagement included: the construction of a product through hands on learning and using real-life relations—which is an amalgamation of STEAM subjects—to pique student interest. For how teachers reflect and revise their STEAM curricula, three categories were created: an evaluation of student work and their ability to make an authentic product, their ability to transfer their learning to various scenarios, and the evaluation of past resources created for lessons. From these categories, themes were developed to help explain the research questions.

The creating, implementing, evaluating, and revising of STEAM curricula are discussed in this section to show how elements of three theoretical frameworks: community of practice theory, constructionism theory, and reflection theory, shaped the design and implementation of the activities for integrating arts and STEM education. The previous chapter presented portraits of four teachers who practice STEAM. As the researcher, I gained insight into their process for creating, implementing, evaluating, and revising their work.

In this chapter, I highlight themes that arose through my findings by presenting an overall analysis of the cases. As I discuss the findings, I revisit the research questions:

4. How do middle school STEM and arts teachers create STEAM, an interdisciplinary curriculum?
    a. How is STEAM defined by middle school teachers?
    b. Why do teachers choose to create STEAM curriculum/lessons?
    c. How do teachers bring STEAM into their content area courses?
5. How do STEAM classrooms function?
    a. How can teachers engage student learning in a STEAM environment?
    b. How does STEAM improve student learning outcomes compared to traditional classrooms (i.e., classrooms that do not teach interdisciplinary curriculum)?
    c. How do STEAM curriculum/lessons shape students' understanding of STEAM fields and their ability to transfer their learning across other learning environments or classes?
6. How do teachers reflect and act on their implementation and assessment of STEAM teaching in order to improve STEAM curriculum/lessons?
    a. How do experienced teachers reflect on their work to improve STEAM curricula?
    b. How do teachers use student work to guide their curriculum revision process?

Resources to Create STEAM

Past Experience

In addressing how middle school STEM and arts teachers create STEAM, this study suggests that by using a diverse set of resources, teachers can create STEAM curricula that equips students with the skills needed to support real life application and ultimately lead to their success. When analyzing the data, it was found that all the participants were in their second careers and most used elements from their past work experience to create STEAM. In the work of Katherine (science), Isabella (art), and David (engineering), they modeled for students the processes they used as professionals in their fields prior to teaching. Many also used their personal hobbies and interests to create interdisciplinary curricula; as mentioned earlier, Justin (mathematics) used his amateur astronomy interest to create various lessons around space. Katherine also used her minor in art history to show how scientists need to be artists and vice versa in her lesson at the Hall of Planet Earth at the Natural History Museum.

Collaboration

Collaboration is a major factor in developing STEAM curricula. Teachers collaborate in varying capacities with their colleagues to not only share resources but also serve as experts to help guide others in their planning. The St. John the Divine Cathedral curriculum development between the art, engineering/technology, and science teachers demonstrates the power of collaboration. These networked interactions of the teachers actively working together with each other mirrored what research has previously found; instead of being passive recipients of expert knowledge in their field, using the information with other teachers in other contexts allows the teachers to make lessons that address broader topics. These interactions provide opportunities for useful discourse related to practice (Mackery & Evans, 2011). With the teachers working together to create curricula that connected together, students were able to literally see how the collaboration of artists, architects, and scientists were necessary to build this monumental cathedral.

By collaborating and learning from each other, teachers can individually apply other disciplines within their class. Discussions and resource sharing with expert teachers allow for teachers not formerly trained in specific disciplines to still be able to deliver content that is “different” from their specialization. There is much data to support the idea that collaboration can be beneficial to develop significant and impactful curricula to best prepare future generations. It is advantageous to break the walls of solo practice (Byrk, 2016), and create spaces where faculty learn from and with each other to promote personal growth (Hadar & Brody, 2010; Patton & Parker, 2017). Through working with peers, teacher learn and build knowledge (Dysthe, 2002), and promote and advocate for the role of developing community, in this case the STEAM community, in supporting learning via interaction and collaboration in this style (Wilson, Ludwig-Hardman, Thornam, & Dunlap, 2004). Paralleling the literature, this study indicates that a partnership with teacher educator(s) provides assistance in answering questions that are relevant to their needs and can serve to place the onus for future action on the teacher themselves in creating curricula (Day, 1999; Mackey & Evans, 2011; Muir, Beswick, & Williamson, 2010; Slevin, 2008). Overall, this has been apparent in the curricula of Katherine, Isabella, and Justin as they each frequently collaborated with each other in different capacities.

In comparison, while David’s interdisciplinary curriculum was not as advanced as the other participants, the STEAM team planning sessions inspired and helped him find new ways to collaborate with his colleagues which ultimately allows for further curriculum development. As supported by research conducted by Mackey and Evans (2011), networking provides a vehicle for gaining knowledge and can act as a bridge to enable the diffusion of new ideas and practices between groups. Overall, the collaboration between teachers plays a large role in motivating individuals to partake in the STEAM process. This is something David was beginning to see and take advantage of for STEAM planning and teaching.

Standards

All participants used their assigned discipline standards to set up and guide their planning and instruction. These standards set the foundation of the content students should be capable of mastering by the end of the year for each grade. All the teachers used this as a starting point for their curricula. Most teachers, David (engineering), Isabella (art), and Katherine (science), consulted the standards from other subjects as well. This further assisted them with determining whether there were overlaps and/or ties they could make with their assigned content area and how they develop STEAM lessons. When Isabella developed her STEAM lesson around botany field guides, she consulted the 7th Grade New York State Science Standards in addition to the Art Standards. Using the New York State Science Standards, she determined what structures of the plant the students needed to know. After, she referred to the Art Standards for the various techniques they could use to sketch them for art class (i.e., shading, perception, etc.).

References to Create STEAM

All participants shared that they use a variety of resources when designing lessons. First, all participants have extensive reference collections including books, pamphlets, handouts, and content standards from a variety of fields other than the one they were assigned to teach. They repeatedly cited these references as resources. In addition, they mentioned visiting libraries, continuously ordering books and information pamphlets on topics they were focusing on from other disciplines that they themselves not familiar with. It was observed and reported during interviews that they also use YouTube and websites. The STEAM planning sessions allowed teachers to share resources and prompted them to use each other more as supportive STEAM colleagues. Even outside the planning sessions, STEAM teachers would solicit recommendations for references sources.

Community Exhibits and Landmarks

All the participants utilized local community exhibits and landmarks for STEAM lessons (i.e., St. John the Divine, Riverside Park, museums—such as the Metropolitan Museum of Art and the American Museum of Natural History). By extending access to resources beyond the immediate school environment, teachers were able to use these as exemplars of STEAM products. It also served as a way to engage students as many were familiar with these landmarks. Consistent with the theoretical framework of communities of practice, extending access to resources and expertise beyond the immediate school environment is beneficial to students learning (Dede et al., 2009; Harlen & Doubler, 2007; Mackey & Evans, 2011).

Professional Development

Professional development (PD) played a major role for many of the teachers who participated in STEAM for this study. This was an opportunity for them to seek knowledge from experts both in their own field and other fields to create interdisciplinary curricula. Out of all the teachers, Katherine (the special education science teacher) and Isabella (the art teacher) regularly participated in PD. They both sought to do workshops in their designated fields and outside of them. As mentioned in these teachers' profiles, the PD workshops had a large influence on their lessons. In their planning time, they used many of the resources they had received from PD as references and when lessons were created and implemented. Sometimes all and/or parts of their presentation and/or handouts received from these events could be found in some of their lessons.

Justin also attended several PDs throughout his career and more recently has been taking computer science classes at local universities. He is working to figure out ways to integrate this focus into his mathematics curricula. In contrast to the other participants, David has not participated in PD outside of the ones offered in the school building. Since the focus group, however, he has been enthusiastic about exploring outside PD offerings.

As mentioned in the findings, the entire sixth-grade faculty attended a joint PD at the Metropolitan Museum of Art (MET), as set up by Katherine, the science teacher. At this event, the teachers gained greater knowledge themselves to further supplement and/or inspire the creation of new STEAM lessons to promote student learning. The findings associated with this research is consistent with the literature on PD participation. PD serves multiple purposes including professional learning to increase productivity, enhanced instruction, and promotion of overall school improvements (Borko, 2004; Little, 2002; MacPhail et al., 2014).

Designated Time to Create STEAM

The last observation made was that all teachers made time in their schedules to create STEAM lessons. In some instances, participants would formerly coordinate their schedules to meet and plan. More often, however, they asynchronously collaborated both pre and post the COVID pandemic. The teachers used collaboration platforms which included email chains, Google documents, and group text messaging. These connections helped to build concepts that connected practices from one context to another similar to findings of Wenger (1998). Additionally, teachers' dual membership in professional and online communities can be conceptualized as boundary spanning which has the potential "to create continuities across boundaries" (p. 105). As research and this study shows, making time to create STEAM leads to community members traversing seemingly intangible or less-traveled boundaries but instead are exposed to new learning opportunities that can be translated or introduced to the practices of their community (Mackey & Evans, 2011) to enrich student learning across multiple content areas.

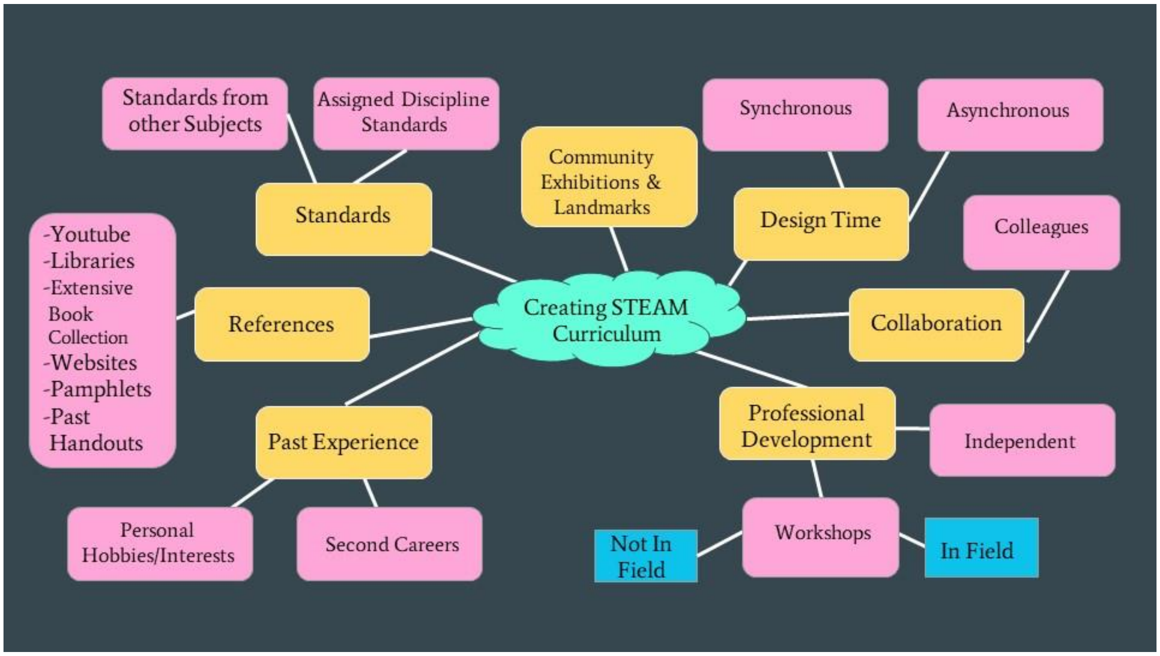
In continuously designing STEAM lessons, all participants recognized the benefit STEAM has in teaching real life applications, such as critical thinking and communication. Katherine's concert hall project taught students how to design and create a building that was aesthetically pleasing but also functional. As discussed earlier, students had to formulate a proposal that considered the audience, resources, and budget--just like professional architects. This taught them how to think critically about obstacles that both current performance spaces faced and ones in their own models. This allowed them to make logical and informed decisions to devise and construct the best product for the context they were creating for. In David's stair design lesson students learned how to work collaboratively in order to design a set of stairs. Using the collaboration of other fields such as math, science, art, to create the stairs and each other to brainstorm the best ideas, allowed students to create the best design and learn deeper through the construction of a product.

Both acknowledged that STEAM lessons are ways to make content more attainable to various types of students. All noted that the special education population had better success in STEAM classrooms as compared to traditional in silo classrooms and teaching of content topics. By designing lessons that allowed students various ways to demonstrate learning, the teachers were better able to assess what the students had learned. As summarized by the science teacher, "STEAM allows [us] to take abstract lessons and make them more tangible for all."

When creating a STEAM curriculum, teachers use a variety of resources. Figure 5.1 is a summary of the various resources mentioned that teachers use to create STEAM.

Figure 5.1

Summary of Resources Teachers Use to Create STEAM



STEAM Classrooms as Hands-on Learning

All teachers provided hands on learning opportunities throughout their curricula which almost immediately drew students into the lessons. As noted by all the participants, students who were typically disengaged from the traditional classroom (teacher-driven lectures) had an increased amount of participation when self-directed, hands-on learning was involved. While lectures were valuable, many students were disengaged during traditional lectures. These findings are consistent with past research that has been done. By stressing the importance of engaging students in creating their own products, Noss and Hyles (1996) have argued that action-oriented activity enables students to participate increasingly in a web of connections to further their activity. Furthermore, Ainley, Pratt, and Hansen (2006) and Mackrell and Pratt

(2016) have argued that learning is best facilitated when the student is engaged in purposeful activity as it leads to them appreciating the ideas they are learning.

Personal Experience through Family Engagement

Another way in which teachers engage students in STEAM education is by making content relatable through personal experience. When children can make connections between what they have learned and how it relates to their own experiences and culture, they mold their metacognition which leads to a lasting understanding (Kafai, 2006). As mentioned in the findings, an exemplar of this type of learning occurred during mathematics class, where students studied the role of dual functionality sundials in the lives of those who invented sundials. Not only were they used to tell time, but they were also used as a form of expression. Sundials are valued as decorative objects but also provided literary metaphors, intrigue, and mathematical study.

By taking a STEAM approach to learning mathematics content (i.e., time, angles, measurement, etc.), the students also gained interdisciplinary lessons in other areas. They not only learned about the histories of various civilizations but also learned about the histories of their own families. This is consistent with research done by Kafai (2005), who also found that learning interactions are not limited to schools alone but extend into community centers and families. In addition, students learned more about their classmates and their diverse backgrounds, a lesson in empathy and equality that the Department of Education and recent movements have been trying to install in our youth (Socio Emotional Learning, n.d.). Through these learning opportunities, students have been exposed to different perspectives, having the experience of wearing someone else’s shoes, where student dialogue about difference and learn about other’s compatible and incompatible experiences (Ackerman, 2001; Mackrell & Pratt, 2016).

Community and Cultural Connections

Another way STEAM teachers engage students is through the use of community and cultural connections. In the findings we saw the impact made when David engaged students using a set of stairs that students passed every day in the park. Similarly, Justin, Isabella, and Katherine made connections with content by using and bringing students to nearby cultural institutions. The experiences students had with these community and cultural products helped students make memorable connections with content that allowed them to create their own authentic products. These lessons further demonstrated the importance of STEAM and served as another example of the importance of breaking the boundaries of traditional in silo classes to create both aesthetically pleasing and functional objects.

Real Life Relations

As briefly alluded to in the mathematics and engineering examples, real life modeling plays a pivotal role in captivating students' attention. Teachers typically present STEAM lessons as problem-based scenarios looking to be solved, similar to what we encounter in our everyday lives. In life, individuals need to be able to adapt and function to different domains. By simulating authentic and real-life problems within the classroom, as David and Justin did in their respective classes, students will be equipped with the skills to adapt and function in different domains (Dolittle & Hicks, 2003). The findings from this study were consistent with that of previous literature on constructionist learning. By supporting students in building their own intellectual structures with materials drawn from their cultures (Kafai, 2005), students are able to discover principles or ideas by themselves. By going through this process, learners make connections with what they already know and can begin to identify with the new content being taught (Kafai, 2005). This sets students up for long term learning that goes beyond the intellectual and includes emotional values (Kafai, 2005).

Special Education

As noted in chapter two, the literature review, one of the major goals of STEAM is to involve the arts in order to increase the participation of students who are traditionally absent from STEM (Perignat & Katz-Buonincontro, 2018). This study confirmed, in all participants, that this was true for students who were classified as Special Education Students. For the St. John the Divine Cathedral, David's students constructed a paper cathedral with more details and elements than that of her peers. In Katherine's class, one student ended up teaching her classmates and even the teacher herself, how to correctly fold certain origami shapes. All participants reported that students with disabilities were constantly engaged throughout lessons. This was also consistent with observations and the artifacts students created. STEAM also provided students multiple modalities to demonstrate learning which was not typical when a subject was taught in silo.

In the engineering class, David shared multiple stories of special education students having success when a STEAM approach was taken to teaching content. One case previously mentioned was the student who designed and built her own cathedral. He would also use examples of everyday items that students would encounter either in their lives or in the community. This especially helped special education students take abstract concepts and make them concrete. For example, one of the projects was designing and creating a model of steps for a potential gym. He used the school's gym as an example and could physically show them the structure in addition to providing lectures and diagrams.

Students of Color

The participation of students of color, as mentioned in the literature, are typically absent from STEM (Perignat & Katz-Buonincontro, 2018). In this study, it was observed that the students of color were usually engaged during STEAM lessons. While there is evidence that students of color were engaged, it is worth noting that the diversity at the school itself is atypical of many public schools. The institution where the study took place is a select school that prioritizes students in districts where there is more economic and racial diversity. Therefore, there is not enough evidence to truly conclude that STEAM made content more relatable and brought in more students of color to STEM fields where persons of color are typically absent.

Transfer of Learning

When participating in STEAM curricula, there is much to be gained. Teachers reported that students frequently transferred their learning of various content and skills between subjects and situations. Sometimes this allowed for concepts to be reinforced in various contexts which helped solidify what the student was learning. It sometimes also allowed teachers to go deeper into certain topics because they had already been exposed and understood the introductory concept. As seen in Isabella's class, she reinforced the concept of scale that had already been discussed in mathematics and science class. She then built on this concept to have students scale perspective drawings.

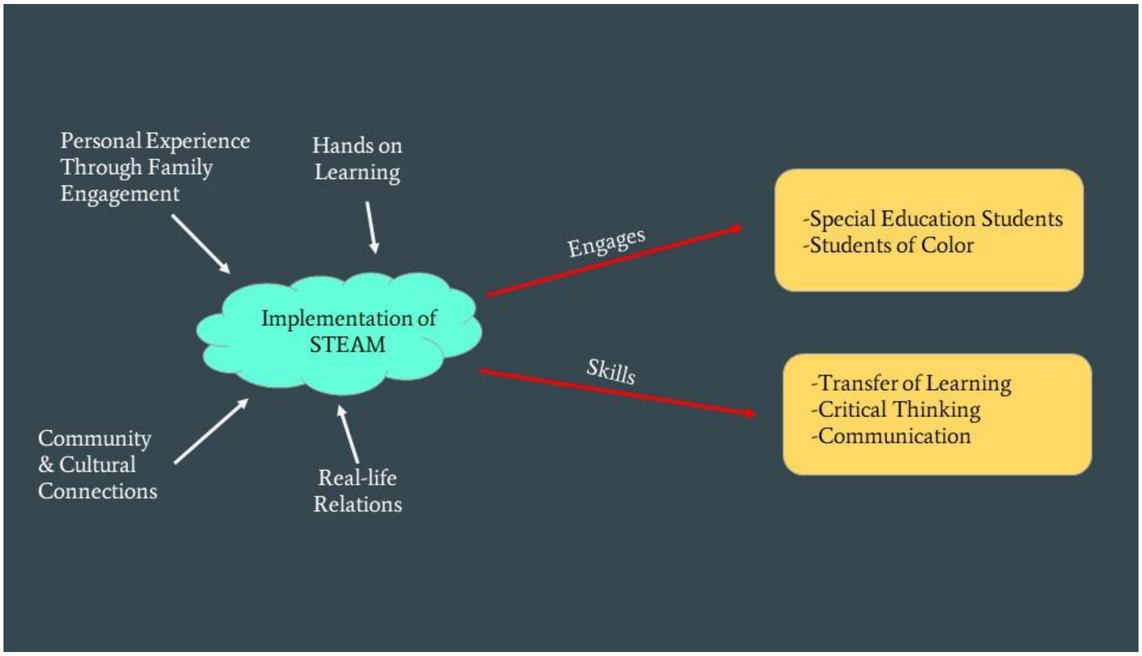
Though various actions when participating in STEAM lessons and activities, the teachers demonstrated through various artifacts shared with me, that students were able to use their personal experience and understanding to interpret the information into their own unique portrayal of reality. This was very apparent in David's engineering class. He often allowed students to follow their interests when partaking in projects. He shared that one of his students who was often disengaged with class took an interest when they were learning about LED lights. The student decided he wanted to create a toilet surrounded by LED’s to assist individuals at night so that they could easily find the commode but not have to turn on all the lights in the bathroom. The actions David took are in line with the research conducted by Bruner (1966): “Through actions, icons, and symbols, people convert reality into their own unique portrayal of reality….it is the teacher’s job to help the learner find the most economical and powerful ways to represent their world…” (Bruner, 1966, as cited in Mackrell & Pratt, 2016).

Also, in line with constructionism theory is making connections with past knowledge to strengthen and deepen future actions. Katherine, the sixth-grade science teacher, learned after several conversations with the seventh-grade science teacher that in the seventh grade teachers were able to eliminate the graphing lesson from the curriculum because the students had come in with a strong background and referenced their knowledge of their sixth-grade STEAM Motion Graph Story projects (a project that had been developed when those current students were in sixth-grade at the time). The following year, the 7th grade teacher made it a point to comment again on the knowledge and examples that had been shared in her class referencing their sixth-grade experience. This allowed the teacher to form new relationships with the content being taught as they had a strong foundational background. In relation to Papert's constructionism theory, this is a typical path in that “learning [ ] build[s] relationships between old and new knowledge, in interactions with others, while creating artifacts of social relevance” (Kafai, 2005 p. 35).

Figure 5.2 provides a summary of how successful implementation in a STEAM classrooms leads to the engagement of students, especially those traditionally absent from STEM, and provides them with the skills needed to be successful.

Figure 5.2

How STEAM Classrooms Function



Note. When implementing STEAM, teachers have many vehicles to engage students (white arrows). This ultimately engages (top yellow box) and provides students with the skills (bottom yellow).

Reflection and Revision to Improve STEAM Curriculum

By taking time to reflect on how lessons went and using authentic work products created by students, teachers are able to understand what students gained from their STEAM curricula and how they can improve their practice to better assist students in succeeding. Authentic work products provided insight into what students obtained from lessons and what knowledge they could transfer in creating authentic work products. Teachers evaluated articles produced by students based on how they were able to make and resemble the real authentic product. Evaluations were done either individually by the teacher using rubrics or standards conceived by either the individual teacher or by the teachers involved with the lesson(s). At times, meetings were also used to discuss and deconstruct the student products.

Once work was collected, Katherine (science) and Isabella (art) would standardize the student's work. Both created rubrics and would provide written feedback. They would also keep general notes about changes that needed to be made and/or kept for the lesson(s). Both teachers also maintained samples of student work from past years. Katherine made sure to keep at least one sample from the following categories: high achieving student, medium achieving student, low achieving student, special education student, and students of diversity. This gives her an overall sample of approximately where students the following year could be coming in. She also informally used their work to see any longitudinal growth. By doing this, she can revise even further.

As stated previously, Isabella also keeps student work. She creates portfolios of her best student's work and uses them when planning for lessons the following year. During one of the deconstruction meetings that I had with Katherine on a joint lesson, she learned about the diverse samples Katherine keeps. She intends on trying out this method to better develop her own STEAM practice and better help target diverse student learning needs.

As mentioned earlier, David, the engineering teacher, likes to re-examine his lessons when they return the following year (or when they eventually occur again). He saves handouts and samples and thinks about what worked and what did not work and what constraints he has placed upon him the year he is delivering the lesson. As compared to Katherine and Isabella, the changes made are typically minimal and tend to be mostly focused on environmental setting constraints (i.e., time, space, material availability). As found in previous research, "it may be that teachers simply do not have a clear understanding of what the reform process looks like in practice, or that other contextual factors limit their intentions to implement reform" (Bobis & Anderson, 2006, as cited in Muir et al., 2010 p. 129). As the teachers reflected during both cycles of this study, David was seemingly excited by the end of the study to do joint reflections with his colleagues and plan for the following year earlier than when the lesson would be delivered again.

During and at the conclusion of evaluations, most teachers determined which portions of the lessons were sufficient to help students obtain content and where revisions could be made in the future. The science and art teacher took extensive notes on what worked and what did not work whereas the mathematics teacher primarily focused on the scores on rubrics that he had created based on the standards of what student were attempting to recreate and the standards of the state. As mentioned earlier, the engineering teacher would reflect at the beginning of when he would revise and/or repeat a lesson, typically occurring the following year. These reflections are consistent with what Hawley and Valli (1999) believed to be

> effective professional learning as it should be based upon students' performance be continuous and supported, be focused on collaborative problem solving, include opportunities for teachers to develop underpinning theoretical understandings, use multiple sources of information, and provide time for teachers to implement new practices (Hawley & Valli, 1999).

Providing planning and evaluation time for teachers has been beneficial for the revision process. At the school, teachers are given professional time several times a month. The STEAM teachers have utilized this time to discuss, create, and evaluate grade-wide STEAM artifacts.

Several of the findings from this study have been consistent with prior literature around the lesson reflections. For the majority of the participants, critical reflection was employed to understand and gain insight for future action. This was similar to previous studies (e.g., Dewey, 1910; Fendler, 2003; Zeichner, 1981) found that "effective professional learning should be grounded in teachers' learning and reflection in classroom practice" (Muir, Beswick, &

Williamson, 2010, as cited in Anderson, 2019). As the teachers in this study worked with each other and participated in research for information beyond the scope of their field, they were able to use this knowledge to strengthen curricula and ultimately help students gain a more global and interdisciplinary understanding that would allow them to be critical thinkers and problem solvers.

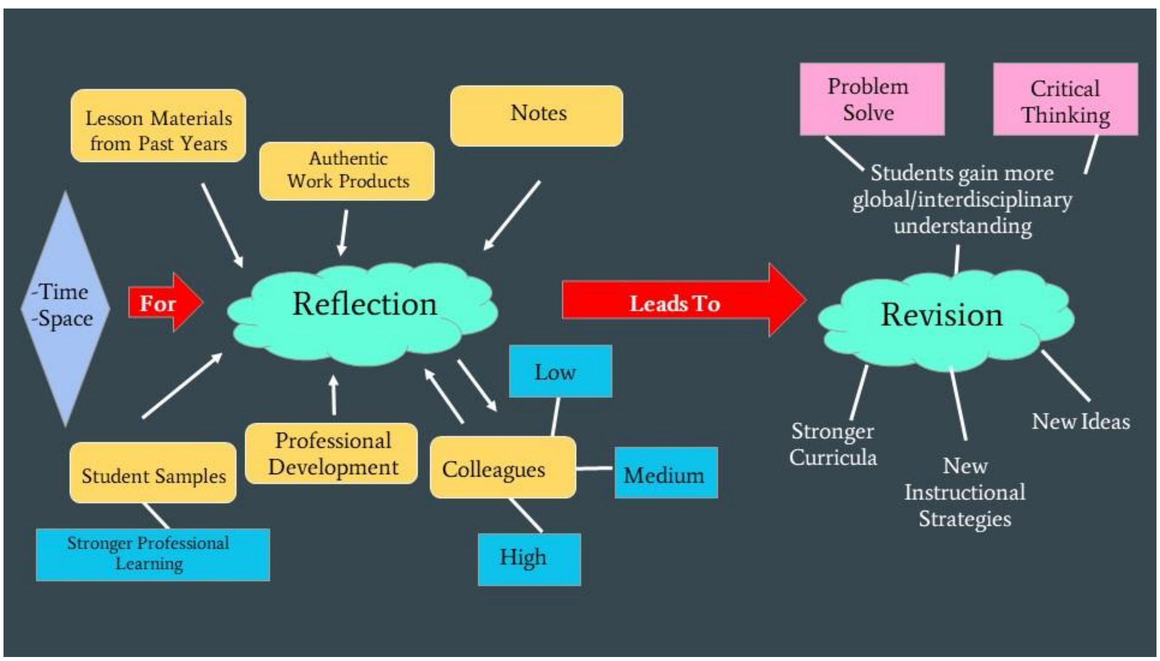
Reflection has also strengthened professional learning among teachers. According to a research done by Lovitt and Clarke (1988), professional learning is most likely to succeed when it takes place close to the teacher's working environment, provides opportunities for reflection and feedback, involves a conscious commitment by the teacher and uses the services of a consultant and/or critical friend. As demonstrated by this study, working collectively with colleagues provided ways to share ideas and identify strategies that each one could use to even align their learning goals even more. Also sharing and hearing about one another's success encouraged others to change some of their instructional strategies in their own classrooms.

Most participants, three of the four, consistently employed the use of teachers from other subjects or other suitably knowledgeable persons, to provide support in planning and implementing classroom experiences which led to the encouraged use of reflection with these individuals and others. The results of this activity were similar to the findings of a study done by Brookfield (1986), in which researchers found that the development of critical reflection on experiences, along with the collaborative interpretation and exchange of such experiences, is one of the most significant forms of adult learning in which individuals can engage.

Lastly, attending professional development has assisted teachers with revising lessons to be more effective. Both Katherine and Isabella frequently attend professional developments offered at nearby institutions and/or through online platforms. As they report, their mindset attending these programs is to learn about new tools and content being offered but also use them to either create new lessons or more often, revise and improve lessons already in existence. As Katherine summarized, “continuously revising lessons seems to make lessons stronger and more meaningful to the students. When they are invested in the lesson, they retain more information and tend to transfer more skills to new situations.” Similarly, Borko et al. (1997) found that professional development experiences that provide opportunities for teachers to explore new instructional strategies and ideas in the context of their own classroom practice were among the most effective for promoting and supporting teacher.

Figure 5.3

How Teachers Reflect and Act on their Implementation and Assessment of STEAM Teaching to Improve STEAM Curriculum/Lessons



Chapter VI

IMPLICATIONS, LIMITATIONS AND FUTURE RESEARCH

The purpose of this study was to understand and describe the process of how five middle school STEM and arts teachers create, implement, evaluate and revise STEAM curricula. The research investigates how creating and employing a STEAM curriculum influenced students' ability to learn content across a diverse array of disciplines. It also investigated ways to evaluate learning in order to understanding where teachers could revise their work to better guide students in their learning process.

Creswell (1998) argues that the nature of qualitative research is "intricate fabric composed of minute threads, many colors, different texture, and various blends of materials" and likewise, is not explained easily or simply (p. 13). This ethnographic case study is an example of detail-oriented teachers who use many threads, colors, textures, and blends to educate students to become scholars and contributing citizens of society. Their cyclical process to create, integrate, and revise STEAM portrays their desire to build a community of practice and become reflectionist to improve their craft while fostering the idea that students can be constructionists and produce authentic materials.

Major Findings of the Research Questions

First, teachers who successfully created STEAM used a variety of resources outside the scope of their field. The sharing of these resources and general discussion among the STEAM community of practice allowed teachers to brainstorm ideas for lessons which ultimately led to the creation of STEAM curricula. Second, successful implementation of STEAM engaged students by using a variety of methods: hands on learning, construction of authentic products, and real-life relations. Third, teachers reflected and evaluated their STEAM lessons on how the implementation of the lesson went and thinking about where challenges arose. Using student work products to help guide the reflection allowed them to better understand when revisions were necessary.

Based on these findings, the research concludes that utilizing the STEAM approach had a significant influence on the creating, teaching, and learning in an urban middle school classroom. Regarding the creation of STEAM, there are a plethora of resources in a variety of different modalities that allow one to create STEAM lessons. While educational resources are valuable to curriculum creation, personal interest, collaboration, and prior experience in other fields (both formal and informal) are equally important when designing STEAM lessons. Therefore, this study suggests that by using a diverse set of resources, teachers can create curricula that equips students with the skills needed to support real life application and ultimately leads to their success.

STEAM implementation has been found to have positively affected student learning and growth as reported by all the teachers which has motivated them to continue doing STEAM for the past several years. STEAM curricula teach students to focus on the process rather than the solution so that they can obtain a deeper understanding of knowledge across various fields in order to be creative thinkers when approaching new scenarios. Unlike the traditional classroom, there are multiple explanations and solutions to problems presented by the STEAM curricula. Students demonstrate and succeed in their learning when they gain the ability to make an argument and support it with copious amounts of supporting evidence. Using STEAM curricula enables teachers to increase student engagement and ultimately leads to an increase in content obtainment. By taking a more global approach, students are able to make more connections with content, building their metacognition and transferring their learning to other disciplines and new situations.

Another major finding of this study indicates that through STEAM, students create authentic work products that require critical and creative thinking. These products can be used to ascertain what students learned and provides insight in helping teachers revise and improve their STEAM curricula over time. This study also provides examples of teachers working either individually or collaboratively to assess and revise their STEAM curricula.

Major Findings Around the STEAM Process

Planning and Teaching

Art is the result of the conscious use of skill and creative imagination to create an aesthetic object. Typically, objects of this caliber evoke emotion that resonates with individuals and causes them to act a certain way. In creating and implementing STEAM curriculum, the arts engage teachers in extensive learning for themselves which can result in the development of more flexible and diverse lessons. Bringing the arts into teacher education exposes them to a broader range of content through which they can relate to. By more deeply connecting teachers with the content they are learning and teaching, teachers are typically emotionally committed to what they are learning which intern allows for a greater commitment to the design and evaluation of their curriculums—a point also made by Justin the mathematics teacher.

In developing STEAM lessons, adding the arts also promotes teacher collaboration and growth of the community of practice. It is impossible to be an expert in every field but working with individual experts in across multiple STEAM fields can assist in making lessons that reach beyond the individual subject area. It also provides individuals access to materials, ideas, and opportunities that were not necessarily available had individuals been working alone.

Student Learning

The use of a STEAM curriculum has proven to be an undeniable opportunity to engage a diverse range of students, many of whom are traditionally missing from the STEM fields. The benefit of adding the arts to STEM is quite significant in that it captivates students' attention through emotion, which was seen in the student products collected from their teachers. By students making interpersonal and intrapersonal connections in this manner, the arts help students mentally process what they are living through in relationship to the new information they are obtaining. This emotional commitment ultimately leads them to making more authentic connections with content and overall drives the production of authentic learning.

Relevance of the Arts to STEAM

Limitations

As for all research, there are limitations that this study cannot control, and which may place restrictions on the possible conclusions. In the study, one limitation based on the design is the fact that I am the principal investigator as well as a colleague of the participants of the study. There is already an established relationship between the participants and researcher, which can be both a limitation and strength of this study. As a limitation, the teacher participants may have held back sharing on where they struggled with STEAM during interviews, the questionnaire, and background information collection because of their apprehension about me being their colleague and peer. In addition, because they knew I was coming to observe them, they may have done more preparation than they typically would have in an ordinary scenario. As a strength, there is already a developed trust and relationship between the teachers and me and among themselves because we have had to all work together in the past in varying capacities. As a result, they are more open to feedback and suggestions because of that pre-existing relationship. Lastly, not using any quantitative methods to quantify how the teachers enacted STEAM pedagogical approaches support students learning can be viewed as a limitation.

Upon reflection of this study, STEAM brought much success to the creation and planning of lessons, but it was not without its challenges along the journey of these teachers. When collaborating, some teachers did not have directed goals or materials that could be easily shared. This sometimes prevented teachers from fully understanding each other's end goals which often left portions of the lessons misaligned. Additionally, there were instances when it was challenging to find direct connections among the various STEAM subjects. Typically, when this occurred, students did not have enough background information to make the connections and teachers found it would take time away from other topics to have to explain the background knowledge.

When analyzing how to build a cohesive STEAM community of practice, it was noteworthy how long and how closely the teachers of this study worked together. Three out of the four had been colleagues on the same grade team for over six years and the fourth teacher, Isabella (art), had joined the first year she taught at the school, three years ago, and had been working with them since. Initially, the teachers focused only on their individual lessons. Slowly (over the past few years), they started working together, sometimes in pairs or triads, which allowed them to build rapport and trust that they would be able to support each other's lessons. Until this study, or over the three years, the STEAM teachers had not yet all worked together on a joint project.

Implications for Future Research

STEAM has made its mark revolutionizing education, but there are still avenues left to be explored. Current standards that incorporate other fields, such as the Next Generation Science

Standards (NGSS), have taken an initiative in revising traditional standards which have typically focused on the individual subjects and not how they coalesce, like they do in real life. NGSS recognizes the importance of including aspects of various other fields (i.e., mathematics and engineering) into their content so students can make connections and see how all subjects work together to create the real-world. One suggestion for future research would be to examine current standards and find overlaps that teachers can reinforce and utilize in the creation and refining of STEAM lessons. This would demonstrate to students how content can be used in various contexts, particularly in solving problems that require multiple perspectives. I would also recommend that when compiling standards, all subjects work together so that no misrepresentation of any subject's content occurs (an issue that was brought up by David about the NGSS and how he considered the NGSS engineering standards as not representative of engineering).

Future research is needed to determine how to build on the NGSS model, in addition to determining how to encompass the arts into the standards and further promote STEAM. The arts have welcomed students who are traditionally absent from STEM fields, as it has the ability to make abstract concepts more understandable. Those developing science or STEM standards should work with educators and professionals in the art fields to equally address all subjects. Professional development programs should invest in providing arts education to STEM educators and vice versa so that all teachers can utilize all subjects in their classrooms to make connections and prepare students for society, where the amalgamation of all subjects are used to solve problems.

When setting up and developing STEAM classrooms, schools should provide teachers with time and space to learn about each other's subjects and to plan lessons together. Teachers can serve as a reference and an expert in their trained fields. They can also be recipients of peer professional development when teaching each other about their subjects. If possible, schools and districts should provide funding for teachers to partake in professional development outside of their field. This would assist them in increasing their content knowledge among other fields so they can develop curriculum that is more global and encompassing of real-world models that require knowledge from a plethora of areas. Lastly, providing adequate supplies and materials for students to construct models and make artifacts is necessary for the STEAM classroom. Students are constantly engaged with learning when they have to build products themselves.

Another area that would benefit from future research would be to promote and expand the scope of the STEAM community of practice beyond the immediate classroom walls. Other countries have done more development in STEAM education and could offer more guidance in growing this type of curriculum. For example, and shown by the art teacher in this study, Isabella was able to offer examples from the Italian standardized curriculum of how her country was able to integrate STEM subjects through the art curriculum. Asia too has done research and had success with the integration of STEAM (Kim & Bolger, 2016) If we were to further study other countries' methods of teaching, perhaps we might find more strategies and methods that could strengthen our professional learning communities and ultimately the students. Since this method is still rather new, the United States has the opportunity to shape and guide others, especially with such a diverse population which is representative of the world.

Teacher education and professional development programs are needed to help prepare preservice and in-service teachers to practice and promote STEAM education. Perhaps exposing them to other fields during their preservice programs and offering professional development to create STEAM can help them foster their own connections and benefit their future teaching endeavors. Equipping experienced and preservice teachers with the tools to identify and implement STEAM resources can help them become better teachers while also encouraging students to push past the classroom walls.

Lastly, this study was based on the development of STEM and art teachers coming together to develop STEAM lessons and their process of creating and implementing a STEAM curriculum. While the primary focus was on the teachers, student learning and achievement continuously came up as teachers presented their observations, artifacts, etc. around students. Therefore, investigating the benefits of a STEAM education from the perspective of students and students of underrepresented groups is suggested. Perhaps examining what causes students to make certain choices in a STEAM environment or understanding why underrepresented students engage with STEAM more than traditional learning would provide additional support in the value of STEAM education.

Implications for STEAM Professional Development (in the Midst of a Pandemic)

In this study, I had the opportunity to redesign my role as not only being both a researcher and teacher but also as becoming a professional development provider. Using my experience as a trained researcher and a practicing classroom teacher, I was able to critically evaluate how the teachers were creating and implementing STEAM and its alignment to prior research. Being a teacher in the same school as the participants added to my ability to guide them as I was familiar with the various policies, guidelines, and restrictions faced in the school setting. Having familiarity in the role of a researcher and teacher allowed me to shape my new role as a professional development (PD) provider.

During the latter part of this study, the educational world was challenged with finding new and creative ways to deliver instruction. The COVID-19 Pandemic forced schools to close and brought school teaching and learning into the home. STEAM provided a unique opportunity for teachers to not only redesign their practice but also find new ways to foster their growth during remote and emergency teaching due to COVID-19 (Luka, 2020; Markham et al., 2020). Having grown as a PD provider, especially during the first phase of the data collection, I was able to assist the teachers during this project. I was able to make suggestions, having seen what worked and did not work for their classrooms. I was also able to help facilitate conversations among all the STEAM fields as I was able to recognize overlaps among the various classrooms. By the end of the second phase, and the height of the pandemic, the teachers were collaboratively working to develop the grade wide COVID chronicles project.

The collaboration of the STEAM teachers during this unusual time in education allowed for a more harmonious transition to remote learning. The inclusion of the various subject areas in collaboration with the teachers allowed each subject and teacher to capitalize on the overlaps found among their subjects. This assisted in student learning by giving students the ability to see how each subject worked in partnership. It also allowed for subjects to contribute more deeply to student learning. In working together, the STEAM teachers found ways for students to transform school classrooms into their homes.

As previously mentioned in the findings, what worked particularly well was having teachers initially share the topics they planned on covering during the pandemic. They did so on a shared Google document and then reached out during meetings and outside of their classes. This allowed for the various subjects to offer specific information to the teacher leading the lesson so they could all further engage their students. In one lesson, Katherine was going to have students design and draw a hospital to treat patients as she previously had students do the same but for the ideal laboratory. When Isabella heard this, she shared that she had taught the students how to make blueprints in art class and that they could use that as the foundation. Justin added that the students had learned about ratios and scaling and suggested he could further expand on blueprints development. With engineering, there was the possibility for the students to construct a paper model as they had done in engineering for the cathedral project, which included further practice in scaling. With everyone's input, the lesson grew from a simple drawing to a more developed lesson that had more application among various fields.

The pandemic exemplified the importance of STEAM given the complex nature of the situation the country. As STEAM is a pedagogy based in creativity to solve problems. Teachers who practiced this type of curricula planning and teaching had an advantage over those who did not or taught lessons for more traditional classrooms. In addition, the teachers practiced STEAM and this added additional benefits in developing stronger and more creative working relationships among colleagues. They took risks and trusted the process of learning and growth within their community of practice. Ultimately, the STEAM lessons not only engaged students during this difficult time but also allowed them to continue learning in this new environment.

Conclusion

In conclusion, since completing this study, these findings clarify how educators define what STEAM education is, starting with the definition of STEAM. Teachers create clearer goals to help direct and educate their students when creating STEAM curricula. This research also provides insight into the process of creating, delivering, evaluating, and revising STEAM lessons. The findings of the study provide models for how STEAM curricula can be created and implemented in the classroom across the various STEAM subjects. Lastly, the study's findings provide ways in which STEAM is evaluated so that the intended goals of STEAM are reached.

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Appendix A Recruitment Email

Young, C.
Teachers College, Columbia University IRB # 20-19

Dear______________________,

My name is Colette Young, and I am currently a 6th grade Science Teacher, 9th grade Regents Living Environment Teacher, and the Middle School Choral Director at Columbia Secondary School. In addition, I am pursuing a Doctor of Education degree in Interdisciplinary Studies in Science and Music Education from Teachers College, Columbia University. As a doctoral student, I am working on a dissertation that seeks to understand the strategies and approaches for creating, implementing, evaluating, and revising Science, Technology, Engineering, Arts, Mathematics (STEAM) curricula. As you are a teacher who does this type of work, I am writing to invite your participation in my study.

This study will take place over the course of the academic school year (May 2020- June 2020). You will be asked to fill out a background data collection sheet and short questionnaire. You will also (a) participate in an individual 45minute individual interview; (b) allow me to observe your planning time for one STEAM lesson; and (c) participate in a focus group. In the latter half of the spring semester, I will repeat parts (b) through (c) for another STEAM lesson of your choosing.

It is important to note, that this is not a requirement of Columbia Secondary School, but rather an opportunity for me to learn from you and your experiences, and the other teachers who may agree to participate, and potentially inform the world of science education on STEAM curriculum development and teaching.

If would like to participate in the research or have any questions, I can be reached at 240-277-1407 or cy2288@tc.columbia.edu

Thank you for your time!

All the best,
Colette Young

Appendix B: Informed Consent

Teachers College, Columbia University
525 West 120th Street
New York NY 10027
212 678 3000

INFORMED CONSENT

Protocol Title:
Exploring the Foundations of Creating, Implementing, and Evaluating STEAM Curricula for the Science, Technology, Engineering, Mathematics, and Arts Education Classroom.

Principal Researcher: ColetteYoung, Teachers College
240-277-1407, coletteyoung@columbiasecondary.org or cy2288@tc.columbia.edu

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INTRODUCTION You are invited to participate in this research study called "Exploring the Foundations of Creating, Implementing, and Evaluating STEAM in the Classroom." You may qualify to take part in this research study because **you have experience creating, implementing, and evaluating Science, Technology, Engineering, the Arts, and Mathematics (STEAM),** you are over 18 years old, have taught for a minimum of 3 years and have graduate training in teaching in any of the STEAM fields**.** Approximately four people will participate in this study and it will take about 3 hours of your time to complete over the course of four months.

WHY IS THIS STUDY BEING DONE? This study is being done to understand the experiences of middle school teachers across multiple content areas implementing STEAM curricula in their classrooms. The strategies and practices that they employ will be examined to understand the process of creating, implementing, and evaluating STEAM in the classroom.

WHAT WILL I BE ASKED TO DO IF I AGREE TO TAKE PART IN THIS STUDY?

If you decide to participate, the primary researcher will observe and discuss your perceptions and experiences around creating, implementing, and evaluating STEAM in an interview.

The researcher will provide you with a background data collection sheet and a questionnaire about your experience with STEAM. This questionnaire will take no longer than 15minutes.

After completion and coordination with the participant, the researcher will arrange to observe your planning time, teaching in the classroom, and evaluation of the STEAM lessons you conduct at a time that is convenient for the participant. The observations will occur wherever you plan, teach, and evaluate your lessons. The observations will go as long as the planning time and lessons last.

After the observations occur, you will be interviewed around how you planned the lesson, implemented, and evaluated the lesson. If you coplanned with other teachers, you will be interviewed in a focus group. If you planned alone, you will be interviewed individually. This interview will be audio-recorded. After the audio recording is written down (transcribed) the audio recording will be deleted. If you do not wish to be audio-recorded, you will still be able to participate. The researcher will just take hand-notes. The interview will take approximately one hour. For all data collected, you will be given a de-identified in order to keep your identity confidential.

The majority of the procedures will be done at Columbia Secondary School in the classroom of your choosing at a time that is convenient to you. **For individual interviews and focus groups, the interviews can be conducted either at the research site or off campus or on an online platform (i.e. Skype, zoom) or over the phone or a combination of either. For the** ***interviews, the researcher will notify you when the audio-recorder is started and stopped. If you do not want to be audio-recorded, the researcher will take hand-notes.*****")**

> **For focus group sessions, the researcher cannot guarantee full confidentiality. I will tell them that "*Your identity will be known to other focus group participants and the researcher(s) cannot guarantee that others in the group will respect the confidentiality of the group. As a researcher, I ask that you will keep all comments made during the focus group confidential and not discuss what happened during the focus group outside the meeting.*"**

This study will not impinge on classroom time. The arrangement is made at the discretion of the participating teacher and study site in order to make sure that the participants do not unfairly miss out on events or scheduled time (e.g., typical classroom lessons) as a result of their participation in the study.

WHAT POSSIBLE RISKS OR DISCOMFORTS CAN I EXPECT FROM TAKING PART IN THIS STUDY?

This is a minimal risk study, which means the harms or discomforts that you may experience are not greater than you would ordinarily encounter in daily life while taking routine physical or psychological examinations or tests. However, there are some risks to consider. You might feel embarrassed to discuss problems that you experienced in creating, implementing, or evaluating STEAM work. You do not have to answer any questions or share anything you do not want to talk about. You can stop participating in the study at any time without penalty. You might feel concerned that things you say might get back to your supervisor. Your information will be kept confidential.

The primary researcher is taking precautions to keep your information confidential and prevent anyone from discovering or guessing your identity, such as using a **de-identified code, a specialized code** composed of random numbers, instead of your name and keeping all information on a password protected computer and locked in a file drawer.

WHAT POSSIBLE BENEFITS CAN I EXPECT FROM TAKING PART IN THIS STUDY?

There is no direct benefit to you for participating in this study. Participation may benefit the field of education to better understand the best way to train STEAM educators.

WILL I BE PAID FOR BEING IN THIS STUDY?
You will not be paid to participate. There are no costs to you for taking part in this study.

WHEN IS THE STUDY OVER? CAN I LEAVE THE STUDY BEFORE IT ENDS? The study is over when you have completed the individual interview or focus group session, filled out the questionnaire, and have had your planning time and class(es) observed. However, you can leave the study at any time even if you have not finished.

PROTECTION OF YOUR CONFIDENTIALITY The primary researcher will keep all written materials locked in a desk drawer in a locked office. Any electronic or digital information (including audio recordings) will be stored on a computer that is password protected. What is on the audio recording will be written down and the audio recording will then be destroyed. There will be no record matching your real name with your pseudonym.

For quality assurance, the study team, the study sponsor (grant agency), and/or members of the Teachers College Institutional Review Board (IRB) may review the data collected from you as part of this study. Otherwise, all information obtained from your participation in this study will be held strictly confidential and will be disclosed only with your permission or as required by U.S. or State law.

Signed informed consent forms will be retained for three years (as per federal regulation) following the close of the study. Once the three years has passed, the signed informed consent forms will be effectively destroyed through shredding.

HOW WILL THE RESULTS BE USED? The results of this study will be published in journals and presented at academic conferences. Your identity will be removed from any data you provide before publication or use for educational purposes. Your name or any identifying information about you will not be published. This study is being conducted as part of the dissertation of the primary researcher.

CONSENT FOR AUDIO AND OR VIDEO RECORDING Audio recording (and/or video recording is part of this research study. You can choose whether to give permission to be recorded. If you decide that you don't wish to be recorded, **you will still be able to participate** in this research study.

______I give my consent to be recorded

____
Signature

______I **do not** consent to be recorded

____
Signature

Teachers College, Columbia University
Institutional Review Board
Protocol Number: 20-019
Consent Form Approved Until: No Expiration Date

WHO MAY VIEW MY PARTICIPATION IN THIS STUDY

___I consent to allow written, video and/or audio-recorded materials viewed at an educational setting or at a conference outside of Teachers College, Columbia University

____
Signature

___I **do not** consent to allow written, video and/or audio-recorded materials viewed outside of Teachers College, Columbia University

____
Signature

OPTIONAL CONSENT FOR FUTURE CONTACT

The primary researcher may wish to contact you in the future. Please initial below to indicate whether or not you give permission for future contact.

The researcher may contact me in the future for information relating to this current study:

Yes ______________________ No______________________
Initial Initial

WHO CAN ANSWER MY QUESTIONS ABOUT THIS STUDY?
If you have any questions about taking part in this research study, you should contact the primary researcher, Colette Young, at 240-277-1407 or at cy2288@tc.columbia.edu.

If you have questions or concerns about your rights as a research subject, you should contact the Institutional Review Board (IRB) (the human research ethics committee) at 212-678-4105 or email IRB@tc.edu or you can write to the IRB at Teachers College, Columbia University, 525 W. 120th Street, New York, NY 10027, Box 151. The IRB is the committee that oversees human research protection for Teachers College, Columbia University.

PARTICIPANT'S RIGHTS

- I have read the Informed Consent Form and have been offered the opportunity to discuss the form with the researcher.
- I have had ample opportunity to ask questions about the purposes, procedures, risks and benefits regarding this research study.

Teachers College, Columbia University
Institutional Review Board
Protocol Number: 20-019
Consent Form Approved Until: No Expiration Date

- I understand that my participation is voluntary. I may refuse to participate or withdraw participation at any time without penalty
- The researcher may withdraw me from the research at their professional discretion.
- If, during the course of the study, significant new information that has been developed becomes available which may relate to my willingness to continue my participation, the researcher will provide this information to me.
- Any information derived from the research study that personally identifies me will not be voluntarily released or disclosed without my separate consent, except as specifically required by law.
- Identifiers may be removed from the data. De-identified data may be used for future research studies, or distributed to another researcher for future research without additional informed consent from you (the research participant or the research participant's representative).
- I should receive a copy of the Informed Consent Form document.

My signature means that I agree to participate in this study:

Print name: ____**Date**: ______________________

Signature:____

Teachers College, Columbia University
Institutional Review Board
Protocol Number: 20-019
Consent Form Approved Until: No Expiration Date

Appendix C: Background Collection Sheet

Participant’s Name

Contact information

- Email:
- Phone Number:

Teaching Experience

- Number of Years Teaching
- Number of Years Teaching STEAM
- How long have you been at your current school?

Before research commences, is there anything you would like to share with the researcher?

Appendix D: STEAM Questionnaire

- How long have you taught STEM?
- How long have you taught STEAM?
- How do you define STEAM?
- What are ways you practice STEAM in your classroom?
- What are some major STEAM lessons you do in your classroom?

Appendix E: Interview Question Guide

Time of interview:
Date:
Place:
Interviewer:
Interviewee:
Position of Interviewee:

Thank you for partaking in my research study. I am working on a dissertation that seeks to understand the strategies and approaches for creating, implementing, evaluating, and revising Science, Technology, Engineering, Arts, Mathematics (STEAM) curricula. As you are a teacher that does this, I am interviewing you to further understand this process.

Questions:

RESEARCH QUESTION #1

- How do you define STEAM?
- What motivated you to do STEAM?
- What was your process to create STEAM lessons?
  - What training/resources methods did you employ to practice STEAM?
  - How do you prepare to incorporate information that you yourself haven't formally studied?
- What are some ways you practice STEAM?
  - What are they doing, how do they describe their practice and definition of STEAM?

RESEARCH QUESTION #2

- What are the differences you see between STEM & STEAM? FMM
- What is one major STEAM lessons you do in your classroom?
  - How did you engage the students in the lesson?
  - How did this lesson improve student learning as compared to teaching the subject matter in silo?
  - How did STEAM shape students' understanding of this topic?

RESEARCH QUESTION #3

- What is your process for reflecting on lessons once they've been executed?
- What is the process you partake in for improving your lessons from year to year?

Closing Remarks:

Thank you so much for participating in this interview. Your responses will not be shared and will be securely locked away. If I have any follow up questions, I will contact you using the information you provided.

Appendix F: Planning Observation Protocol

Class______________________

Date_______________________

Period in Planning Observation______________________

This Observation Protocol will be used during the observation to guide the researcher in identifying how teachers plan and create STEAM curricula.

PHYSICAL SETTING What the environment looks like • context • Space allocations • Objects, resources, technologies are in the setting	
PARTICIPANTS • Who is there? • What are their roles • What brings people together • Who is NOT here that you would expect to participate? • How are the people organized?	
ACTIVITIES/INTERACTIONS • What's happening? • Is there an agenda? • How are people interacting with the activity/with others? • How are people & activities connected? • What norms/rules structure the activity/interactions? • When did the activity begin? • How long does it last? Is it typical?	
CONVERSATION • Content being spoken • Who speaks to whom? • Who listens? • Note silences and non-verbal behaviors	
SUBTLE Factors: • Informal/unplanned activities • Symbolic and connotative meanings • Nonverbal communications • What does not happen	

Appendix G: Planning Observation Checklist

Class______________________

Date_______________________

Period in the Planning Observation_____________________

This Planning Observation Checklist will be used in conjunction with the Planning Observation Protocol during the planning observation(s) to guide the identification of how teachers create STEAM curricula.

✔	**Activity**	**Notes**
	Providing options to students	
	Creating STEAM problem scenarios	
	Elements of STEAM	
	Review and Considers Content Standards	
	Research issues relevant to your locale and connect to standards	
	Brainstorm ways to integrate issues with standards	
	Involving the community	
	Teacher Collaboration (i.e.,, teacher to teacher, teacher to guest artist	
	Reflect from last time the lesson(s) was done	
	Understand the needs of the students	
	Engage in Professional Development	
	Partnership between STEAM subjects	
	Culture and communication	

Appendix H: Classroom Observation Protocol

Class______________________

Date______________________

Period in the Classroom Observation____________________

This Classroom Observation Protocol will be used during the classroom observation(s) to understand how teachers implement their planning of STEAM curricula within the classroom setting.

PHYSICAL SETTING What the environment looks like • context • Space allocations • Objects, resources, technologies are in the setting	
PARTICIPANTS • Who is there? • What are their roles • What brings people together • Who is NOT here that you would expect to participate? • How are the people organized?	
ACTIVITIES/INTERACTIONS • What's happening? • Is there an agenda? • How are people interacting with the activity/with others? • How are people & activities connected? • What norms/rules structure the activity/interactions? • When did the activity begin? • How long does it last? Is it typical?	
CONVERSATION • Content being spoken • Who speaks to whom? • Who listens? • Note silences and non-verbal behaviors	
SUBTLE Factors: • Informal/unplanned activities • Symbolic and connotative meanings • Nonverbal communications • What does not happen	

Appendix I: Classroom Observation Checklist

Class______________________

Date_______________________

Period in the Classroom Observation____________________

This Classroom Observation Checklist will be used in conjunction with the Classroom Observation Protocol to guide the identification of how teachers implement STEAM curricula.

✔	**Activity**	**Notes**
	Student Engagement	
	Increase of minority groups interested in STEM	
	Students make socially and culturally relevant connections to content (authentic discipline integration by the students)	
	Students problem solve using divergent thinking in order to seek multiple solutions to problems	
	Students collaborate when solving problems	
	Students are critical in analyzing their work	
	All subjects are being equally taught	
	Students are able to make connections to components of STEAM (interdisciplinary nature)	
	Incorporation of 21st Century Skills (i.e.,, collaboration, creativity, problem solving)	
	The art or design should be because of STEAM content (not just prettying it up) and serve a function in helping students learn	

Appendix J: Artifact Checklist

Class______________________

Date______________________

Description of the Artifact:

This Classroom Observation Checklist will be used in conjunction with the Classroom Observation Protocol to guide the identification of how teachers implement STEAM curricula.

✔	**Activity**	**Notes**
	Students make socially and culturally relevant connections to content (authentic discipline integration by the students)	
	Student applied knowledge and skills they learned during the STEAM unit	
	Artifact created represents a real-world problem	
	Students demonstrated self-expression through the artifacts	
	Artifact met the standards of multiple STEAM disciplines	
	All subjects are being equally represented	
	Students are able to make connections to components of STEAM (interdisciplinary nature)	
	The art or design should be because of STEAM content (not just prettying it up) and serve a function in helping students learn	

Appendix K: Focus Group Discussion Points

Time of interview:
Date:
Place:
Interviewer:
Interviewee:
Position of Interviewee:

Questions:

How do you define STEAM?

How do you bring STEAM into your content area courses?

- What is your process for creating STEAM lessons?

What does your STEAM classroom look like?

How do you measure if your STEAM lesson was successful?

Mini Scenario Activity.

How would you design a lesson(s) around the following scenario for your STEAM classroom?

> "Sadly the elephants, Lady Bird and Joy, have died. As a result, there is a large open space open. The zoo wants to fill the space with a new animal but doesn't know which animal to choose. The zookeepers are inviting middle school schools to weigh in on the decision. The 6th grade at Glenview Middle School will help to select the animal. As part of this project, you will research what animal should move into this space. To do so, you need to examine what the recommendations are for the animals' living space, and understand the animals' living habitats and life cycles. After coming up with the list of possible animals, you will survey the entire school to see which animal should live in the enclosure, and then create an interactive presentation to convince the zookeepers of this choice" (Quigley & Herro, 2019, p. 13).

Appendix L: Engineering Standards

National Content Standards
K-12 Engineering/Engineering Technology
American Society of Engineering Education (ASEE)

Technology Education Program Checklist

ASEE K-12 Engineering/Engineering Technology Standards Statements			
1) Engineering Design **Declarative Statements** **Standard One: Students will develop an understanding of engineering design.** **Students will understand the basic concept of:**			
1D1: Design and how to conduct experiments, as well as to analyze and interpret data as it relates to engineering design.			
1D2: Designing, testing, and building a system, component, or process to meet desired needs within realistic constraints.			
1D3: Identifying and formulating engineering problems as they relate to engineering design.			
1D4: Applying iteration as a part of an engineering design process.			
1D5: Suggesting and evaluating alternative solutions.			
1D6: Optimizing a solution as it relates to engineering design.			
1D7: Problem solving and that not all problems can be solved with engineering design.			
1D8: Optimal solutions depend on outcomes and perspectives. For example, engineers, funding sources, project managers, and political and others are potential influences on outcomes or solutions			
Procedural Statements **Standard One: Students will apply the engineering design process, troubleshooting, research and development, invention and innovation, and experimentation in problem solving and engineering design.** **Students will:**			
1P1: Learn that the engineering design process includes defining a problem, brainstorming, researching and generating ideas, identifying criteria and specifying constraints, exploring possibilities, selecting an approach, developing a design proposal, making a model or prototype, testing and evaluating the design using specifications, refining the design, creating or making it, and communicating processes and results.			
1P2: Ask questions and make observations to help figure out how things work.			
1P3: Learn that all products and systems are subject to failure and that many products and systems can be fixed.			
1P4: Troubleshoot as a way of finding out why something does not work so that it can be fixed.			
1P5: Use the process of experimentation, which is common in science, to solve engineering problems.			
1P6: Apply the engineering design process using a variety of strategies, such as problem-solving, creative thinking, visual imagery, critical thinking, and reasoning.			
1P7: Apply invention as a process of turning ideas and imagination into devices and systems.			
1P8: Apply innovation to modify an existing product or system to improve it.			
1P9: Apply research and development as a specific problem-solving approach.			

2D9: Understanding of how knowledge acquired in one context, such as biology, is applied in another context, such as biotechnology. For example, the biotechnology industry is learning the importance of properly applying production techniques with bioprocesses and the problems that can occur in producing a product.			
2D10: Understanding of how things work or why things work the way they do and how design solutions rely upon the knowledge of science, technology, and mathematics and prior results.			
2D11: System thinking involves thinking about things as systems, which means looking for how every part relates to others.			
2D12: Something may not work well or at all if a part of it is missing, broken, worn out, mismatched, or misconnected.			
Procedural Statements **Standard Two: Students will be able to apply concepts of science, technology, and mathematics in an engineering design process.** **Students will:**			
2P1: Apply their knowledge of science, technology, engineering, and mathematics when solving practical problems.			
2P2: Analyze and solve formulated engineering problems.			
2P3: Use contemporary engineering tools, such as, computer-aided drawing (CAD), computer aided manufacturing (CAM), calculators, and spreadsheets to communicate and demonstrate their use of science, technology, and mathematics knowledge.			

3) Nature of Engineering **Declarative Statements** **Standard Three: Students will develop an understanding of the characteristics and broad scope of engineering.** **Students will understand that:**			
3D1: Engineering is the knowledge of natural science and mathematics gained by study, experience, and practice that are applied with creativity and judgment to develop ways to utilize the materials and forces of nature for the benefit of human kind. An engineer is a person who is trained in and uses scientific and technological knowledge to solve practical problems.			
3D2: Public perception of engineers and engineering among global cultures is diverse and not consistent.			
3D3: Engineering and engineering technology disciplines have a common core of knowledge and areas of specializations.			
3D4: Engineering and human capabilities are in a cyclical relationship that influences each other over time.			
3D5: Engineering permeates all aspects of society.			
3D6: Engineering solutions have continually improved the quality of life, added business value, and significantly influenced the global economy.			
3D7: Engineering has intended and unintended consequences.			
3D8: Lifelong learning results in purposeful experiences in science, technology, engineering, and mathematics that lead to doing reflections of and building on prior knowledge in order to make improvements to human existence.			

American Society of Heating, Refrigerating, and Air-condition Engineers, Inc. (ASHRAE) Handbook, American National Standards Institute (ANSI) Standards, and related professional codes.			
4D5: Engineered outcomes must be documented to accepted standards with precision in order to aid in avoiding unnecessary harm.			
4D5: Communication of ideas is effective when proper media is used.			
4D6: Multidisciplinary and cross-functional teams bring a variety of skills and perspectives that enhance the engineering process.			
Procedural Statements **Standard Four: Students are able to use effective communication and teamwork skills to acquire information and convey engineered outcomes to a variety of stakeholders.** **Students will be able to:**			
4P1: Use appropriate communication procedures, such as, research, presentations, and documentation protocols.			
4P2: Follow patent process and recognize the need for proper documentation.			
4P3: Follow drafting standards and recognize the need for following procedures and protocols.			
4P4: Use professional standards, such as ANSI and ASHRAE to aid communication.			
4P5: Follow professional codes, such as, those for the International Fire Code (IFC).			
4P6: Follow style manuals in writing, such as, those provided by the American Psychological Association (APA) publication manual.			
4P6: Communicate effectively using multiple media.			
4P7: Practice interpersonal and group dynamic skills, such as,			

cooperate with others, advocate and influence, resolve conflict, and negotiate.			
4P8: Practice interpersonal and group dynamic skills, such as, cooperate with others, advocate and influence, resolve conflict, and negotiate.			
4P9: Function on multidisciplinary and cross-functional teams			
5) Engineering and Society **Declarative Statements** **Standard Five: Students will develop an understanding that engineering is an ethical human endeavor that addresses the needs of a global society.** **Students will understand that:**			
5D1: Engineering is a human endeavor that has always been practiced as long as humans have had needs.			
5D2: Results and use of engineered products and systems impact global, economic, cultural, environmental, and societal contexts in both expected and unexpected ways.			
5D3: Professional ethics and societal obligations and responsibilities must be considered in the development and use of engineered solutions to human needs and wants, such as, safety, health, comfort, and mobility.			
5D4: Engineering itself is neither positive nor negative, but the use of engineered outcomes can have desirable and undesirable consequences.			
5D5: Development and use of engineered products and systems affect the way people of different cultures live, the kind of work they do, and the decisions they have to make.			
5D6: Public perception of engineering and of engineers among global cultures varies greatly depending on the historical impacts and the			

desirable and undesirable engineered developments, such as advances in medicine, public health, consumer goods, resources, energy, and changes in social mores.			
Procedural Statements **Standard Five: Students will be able to investigate and analyze the impact of engineering on a global society.** **Students will:**			
5P1: Investigate and analyze the impact of engineering from multiple perspectives, such as, economic, environmental, social, political, ethical, health and safety, manufacturability and sustainability.			
5P2: Identify constraints and external factors and explain how they impact engineering outcomes, such as, economic, societal attitudes, and optimization.			
5P3: Investigate and study the positive and negative results of engineering.			
5P4: Learn that ethical considerations are important in the development, selection, and use of engineered products and systems.			
5P5: Analyze the transfer of an engineered outcome from one society to another and how it may affect positively or negatively both societies, such as, the sharing of flash freezing of food and how societies changed as a result.			

K-12 Engineering/Engineering Technology Standards Meeting
October 15-18, 2006, Peabody Court Hotel, Baltimore, MD
The National Content Standards for K-12 Engineering/Engineering Technology initial development meeting convened by the Corporate Member Council (CMC) of the American Society of Engineering Education (ASEE) and the National Association of State Directors of Career Technical Education Consortium (NASDCTEc).

Mathematics - Grade 6: Introduction

In Grade 6, instructional time should focus on four critical areas: (1) connecting ratio and rate to whole number multiplication and division and using concepts of ratio and rate to solve problems; (2) completing understanding of division of fractions and extending the notion of number to the system of rational numbers, which includes negative numbers; (3) writing, interpreting, and using expressions and equations; and (4) developing understanding of statistical thinking.

1. Students use reasoning about multiplication and division to solve ratio and rate problems about quantities. By viewing equivalent ratios and rates as deriving from, and extending, pairs of rows (or columns) in the multiplication table, and by analyzing simple drawings that indicate the relative size of quantities, students connect their understanding of multiplication and division with ratios and rates. Thus students expand the scope of problems for which they can use multiplication and division to solve problems, and they connect ratios and fractions. Students solve a wide variety of problems involving ratios and rates.

2. Students use the meaning of fractions, the meanings of multiplication and division, and the relationship between multiplication and division to understand and explain why the procedures for dividing fractions make sense. Students use these operations to solve problems. Students extend their previous understandings of number and the ordering of numbers to the full system of rational numbers, which includes negative rational numbers, and in particular negative integers. They reason about the order and absolute value of rational numbers and about the location of points in all four quadrants of the coordinate plane.

3. Students understand the use of variables in mathematical expressions. They write expressions and equations that correspond to given situations, evaluate expressions, and use expressions and formulas to solve problems. Students understand that expressions in different forms can be equivalent, and they use the properties of operations to rewrite expressions in equivalent forms. Students know that the solutions of an equation are the values of the variables that make the equation true. Students use properties of operations and the idea of maintaining the equality of both sides of an equation to solve simple one-step equations. Students construct and analyze tables, such as tables of quantities that are in equivalent ratios, and they use equations (such as $3x = y$) to describe relationships between quantities.

4. Building on and reinforcing their understanding of number, students begin to develop their ability to think statistically. Students recognize that a data distribution may not have a definite center and that different ways to measure center yield different values. The median measures center in the sense that it is roughly the middle value. The mean measures center in the sense that it is the value that each data point would take on if the total of the data values were redistributed equally, and also in the sense that it is a balance point. Students recognize that a measure of variability (interquartile range or mean absolute deviation) can also be useful for summarizing data because two very different sets of data can have the same mean and median yet be distinguished by their variability. Students learn to describe and summarize numerical data sets, identifying clusters, peaks, gaps, and symmetry, considering the context in which the data were collected.

Students in Grade 6 also build on their work with area in elementary school by reasoning about relationships among shapes to determine area, surface area, and volume. They find areas of right triangles, other triangles, and special quadrilaterals by decomposing these shapes, rearranging or removing pieces, and relating the shapes to rectangles. Using these methods, students discuss, develop, and justify formulas for areas of triangles and parallelograms. Students find areas of polygons and surface areas of prisms and pyramids by decomposing them into pieces whose area they can determine. They reason about right rectangular prisms with fractional side lengths to extend formulas for the volume of a right rectangular prism to fractional side lengths. They prepare for work on scale drawings and constructions in Grade 7 by drawing polygons in the coordinate plane.

Mathematical Practices

1. Make sense of problems and persevere in solving them.
2. Reason abstractly and quantitatively.
3. Construct viable arguments and critique the reasoning of others.
4. Model with mathematics.
5. Use appropriate tools strategically.
6. Attend to precision.
7. Look for and make use of structure.
8. Look for and express regularity in repeated reasoning.

Grade 6 Overview

Ratios and Proportional Relationships
• Understand ratio concepts and use ratio reasoning to solve problems.

The Number System
• Apply and extend previous understandings of multiplication and division to divide fractions by fractions.
• Compute fluently with multi-digit numbers and find common factors and multiples.
• Apply and extend previous understandings of numbers to the system of rational numbers.

Expressions and Equations
• Apply and extend previous understandings of arithmetic to algebraic expressions.• Reason about and solve one-variable equations and inequalities.
• Represent and analyze quantitative relationships between dependent and independent variables.

Geometry
• Solve real-world and mathematical problems involving area, surface area, and volume.

Statistics and Probability
• Develop understanding of statistical variability.
• Summarize and describe distributions.

Ratios & Proportional Relationships 6.RP

Understand ratio concepts and use ratio reasoning to solve problems.

1. Understand the concept of a ratio and use ratio language to describe a ratio relationship between two quantities. *For example, "The ratio of wings to beaks in the bird house at the zoo was 2:1, because for every 2 wings there was 1 beak." "For every vote candidate A received, candidate C received nearly three votes."*
2. Understand the concept of a unit rate a/b associated with a ratio a:b with $b \neq 0$, and use rate language in the context of a ratio relationship. *For example, "This recipe has a ratio of 3 cups of flour to 4 cups of sugar, so there is 3/4 cup of flour for each cup of sugar." "We paid $75 for 15 hamburgers, which is a rate of $5 per hamburger."*[1]
3. Use ratio and rate reasoning to solve real-world and mathematical problems, e.g., by reasoning about tables of equivalent ratios, tape diagrams, double number line diagrams, or equations.
   a. Make tables of equivalent ratios relating quantities with whole-number measurements, find missing values in the tables, and plot the pairs of values on the coordinate plane. Use tables to compare ratios.
   b. Solve unit rate problems including those involving unit pricing and constant speed. *For example, if it took 7 hours to mow 4 lawns, then at that rate, how many lawns could be mowed in 35 hours? At what rate were lawns being mowed?*
   c. Find a percent of a quantity as a rate per 100 (e.g., 30% of a quantity means 30/100 times the quantity); solve problems involving finding the whole, given a part and the percent.
   d. Use ratio reasoning to convert measurement units; manipulate and transform units appropriately when multiplying or dividing quantities.

[1] Expectations for unit rates in this grade are limited to non-complex fractions.

Apply and extend previous understandings of multiplication and division to divide fractions by fractions.
1. Interpret and compute quotients of fractions, and solve word problems involving division of fractions by fractions, e.g., by using visual fraction models and equations to represent the problem. *For example, create a story context for (2/3) ÷ (3/4) and use a visual fraction model to show the quotient; use the relationship between multiplication and division to explain that (2/3) ÷ (3/4) = 8/9 because 3/4 of 8/9 is 2/3. (In general, (a/b) ÷ (c/d) = ad/bc.) How much chocolate will each person get if 3 people share 1/2 lb of chocolate equally? How many 3/4-cup servings are in 2/3 of a cup of yogurt? How wide is a rectangular strip of land with length 3/4 mi and area 1/2 square mi?*

Compute fluently with multi-digit numbers and find common factors and multiples.
2. Fluently divide multi-digit numbers using the standard algorithm.
3. Fluently add, subtract, multiply, and divide multi-digit decimals using the standard algorithm for each operation.
4. Find the greatest common factor of two whole numbers less than or equal to 100 and the least common multiple of two whole numbers less than or equal to 12. Use the distributive property to express a sum of two whole numbers 1–100 with a common factor as a multiple of a sum of two whole numbers with no common factor. *For example, express 36 + 8 as 4 (9 + 2).*

Apply and extend previous understandings of numbers to the system of rational numbers.
5. Understand that positive and negative numbers are used together to describe quantities having opposite directions or values (e.g., temperature above/below zero, elevation above/below sea level, credits/debits, positive/negative electric charge); use positive and negative numbers to represent quantities in real-world contexts, explaining the meaning of 0 in each situation.
6. Understand a rational number as a point on the number line. Extend number line diagrams and coordinate axes familiar from previous grades to represent points on the line and in the plane with negative number coordinates.
   a. Recognize opposite signs of numbers as indicating locations on opposite sides of 0 on the number line; recognize that the opposite of the opposite of a number is the number itself, e.g., –(–3) = 3, and that 0 is its own opposite.
   b. Understand signs of numbers in ordered pairs as indicating locations in quadrants of the coordinate plane; recognize that when two ordered pairs differ only by signs, the locations of the points are related by reflections across one or both axes.
   c. Find and position integers and other rational numbers on a horizontal or vertical number line diagram; find and position pairs of integers and other rational numbers on a coordinate plane.
7. Understand ordering and absolute value of rational numbers.
   a. Interpret statements of inequality as statements about the relative position of two numbers on a number line diagram. *For example, interpret –3 > –7 as a statement that –3 is located to the right of –7 on a number line oriented from left to right.*
   b. Write, interpret, and explain statements of order for rational numbers in real-world contexts. *For example, write –3 °C > –7 °C to express the fact that –3 °C is warmer than –7 °C.*
   c. Understand the absolute value of a rational number as its distance from 0 on the number line; interpret absolute value as magnitude for a positive or negative quantity in a real-world situation. *For example, for an account balance of –30 dollars, write |–30| = 30 to describe the size of the debt in dollars.*
   d. Distinguish comparisons of absolute value from statements about order. *For example, recognize that an account balance less than –30 dollars represents a debt greater than 30 dollars.*
8. Solve real-world and mathematical problems by graphing points in all four quadrants of the coordinate plane. Include use of coordinates and absolute value to find distances between points with the same first coordinate or the same second coordinate.

Expressions & Equations 6.EE

Apply and extend previous understandings of arithmetic to algebraic expressions.

1. Write and evaluate numerical expressions involving whole-number exponents.
2. Write, read, and evaluate expressions in which letters stand for numbers.
   a. Write expressions that record operations with numbers and with letters standing for numbers. *For example, express the calculation "Subtract y from 5" as $5 - y$.*
   b. Identify parts of an expression using mathematical terms (sum, term, product, factor, quotient, coefficient); view one or more parts of an expression as a single entity. *For example, describe the expression $2(8 + 7)$ as a product of two factors; view $(8 + 7)$ as both a single entity and a sum of two terms.*
   c. Evaluate expressions at specific values of their variables. Include expressions that arise from formulas used in real-world problems. Perform arithmetic operations, including those involving whole-number exponents, in the conventional order when there are no parentheses to specify a particular order (Order of Operations). *For example, use the formulas $V = s^3$ and $A = 6s^2$ to find the volume and surface area of a cube with sides of length $s = 1/2$.*

3. Apply the properties of operations to generate equivalent expressions. *For example, apply the distributive property to the expression $3(2 + x)$ to produce the equivalent expression $6 + 3x$; apply the distributive property to the expression $24x + 18y$ to produce the equivalent expression $6(4x + 3y)$; apply properties of operations to $y + y + y$ to produce the equivalent expression $3y$.*
4. Identify when two expressions are equivalent (i.e., when the two expressions name the same number regardless of which value is substituted into them). *For example, the expressions $y + y + y$ and $3y$ are equivalent because they name the same number regardless of which number y stands for.*

Reason about and solve one-variable equations and inequalities.

5. Understand solving an equation or inequality as a process of answering a question: which values from a specified set, if any, make the equation or inequality true? Use substitution to determine whether a given number in a specified set makes an equation or inequality true.
6. Use variables to represent numbers and write expressions when solving a real-world or mathematical problem; understand that a variable can represent an unknown number, or, depending on the purpose at hand, any number in a specified set.
7. Solve real-world and mathematical problems by writing and solving equations of the form $x + p = q$ and $px = q$ for cases in which p, q and x are all nonnegative rational numbers.
8. Write an inequality of the form $x > c$ or $x < c$ to represent a constraint or condition in a real-world or mathematical problem. Recognize that inequalities of the form $x > c$ or $x < c$ have infinitely many solutions; represent solutions of such inequalities on number line diagrams.

Represent and analyze quantitative relationships between dependent and independent variables.

9. Use variables to represent two quantities in a real-world problem that change in relationship to one another; write an equation to express one quantity, thought of as the dependent variable, in terms of the other quantity, thought of as the independent variable. Analyze the relationship between the dependent and independent variables using graphs and tables, and relate these to the equation. For example, in a problem involving motion at constant speed, list and graph ordered pairs of distances and times, and write the equation $d = 65t$ to represent the relationship between distance and time.

Geometry 6.G

Solve real-world and mathematical problems involving area, surface area, and volume.

1. Find the area of right triangles, other triangles, special quadrilaterals, and polygons by composing into rectangles or decomposing into triangles and other shapes; apply these techniques in the context of solving real-world and mathematical problems.
2. Find the volume of a right rectangular prism with fractional edge lengths by packing it with unit cubes of the appropriate unit fraction edge lengths, and show that the volume is the same as would be found by multiplying the edge lengths of the prism. Apply the formulas $V = l\ w\ h$ and $V = b\ h$ to find volumes of right rectangular prisms with fractional edge lengths in the context of solving real-world and mathematical problems.
3. Draw polygons in the coordinate plane given coordinates for the vertices; use coordinates to find the length of a side joining points with the same first coordinate or the same second coordinate. Apply these techniques in the context of solving real-world and mathematical problems.
4. Represent three-dimensional figures using nets made up of rectangles and triangles, and use the nets to find the surface area of these figures. Apply these techniques in the context of solving real-world and mathematical problems.

Statistics & Probability 6.SP

Develop understanding of statistical variability.

1. Recognize a statistical question as one that anticipates variability in the data related to the question and accounts for it in the answers. *For example, "How old am I?" is not a statistical question, but "How old are the students in my school?" is a statistical question because one anticipates variability in students' ages.*
2. Understand that a set of data collected to answer a statistical question has a distribution which can be described by its center, spread, and overall shape.
3. Recognize that a measure of center for a numerical data set summarizes all of its values with a single number, while a measure of variation describes how its values vary with a single number.

Summarize and describe distributions.

4. Display numerical data in plots on a number line, including dot plots, histograms, and box plots.
5. Summarize numerical data sets in relation to their context, such as by:
    a. Reporting the number of observations.
    b. Describing the nature of the attribute under investigation, including how it was measured and its units of measurement.
    c. Giving quantitative measures of center (median and/or mean) and variability (interquartile range and/or mean absolute deviation), as well as describing any overall pattern and any striking deviations from the overall pattern with reference to the context in which the data were gathered.
    d. Relating the choice of measures of center and variability to the shape of the data distribution and the context in which the data were gathered.

Name: Class: Date:

BUILDING A SUNDIAL

Constructing the dial

The dial is the part of the sundial on which a shadow is cast to tell the time.

1. Turn a blank piece of paper so that its longer sides are the top and bottom (landscape orientation).

2. Use a ruler to find a point that is 4 cm from the top edge and 4 cm from the left edge. Label this point L. Find a second point that is 4 cm from the top edge and 4 cm from the right edge. Label this point R. Write your names to the right of point L.

3. Use a ruler to find the center of your paper, and label this point C.

4. Use a compass to construct a circle with center C and radius 8 cm.

5. Use a straightedge to draw a radius from C straight down toward the bottom edge of the paper. Label the point of intersection with the circle "noon."

6. Use a straightedge to draw a long line tangent to the circle at "noon." The line should be parallel to the bottom of the page and just touch the circle at "noon."

7. Draw six more radii of the circle C so that there are six 15-degree central angles extending toward the bottom of the circle. Extend these radii so that they intersect with the tangent drawn in step 5.

8. Label the points of intersection of the radii and the tangent as you would a clock.

9. Choose a short motto or saying that expresses some wisdom relating to the passage of time, or the sky. Your motto may be in any language. Record your motto on your dial so that it does not obscure the scaled tangent line.

Constructing the gnomon

The gnomon is the part of the sundial that casts a shadow on the dial.

SAFETY FIRST! These wooden skewers are sharp. Please do not treat them as toys. Be more careful with them than you think is necessary.

1. You will need to preserve the wrapper of your straw. Unwrap your straw carefully so that the wrapper remains long and intact.

2. Curl the wrapper so that it's long and skinny. Insert the wrapper inside the straw. This will help the straw cast a darker shadow.

3. Carefully pierce the straw near the middle with the wooden skewer. Slowly and gently push the straw along the skewer for about 10 cm.

Finishing your sundial

1. Use a ruler to find the center of your foam board. Use a pen to mark the center.

2. Place your dial on top of the foam board so that the center of the foam board coincides with C.

3. Carefully and slowly poke your skewer straight down through C and the foam board. Your skewer should stick out the bottom about 8 cm.

4. Rotate your dial so that the edges of the paper are parallel to the edges of the foam board.

5. Carefully and slowly poke two more skewers straight down through L and R and the foam board. Your skewers should stick out the bottom exactly 14.5 cm.

TESTING OUR SUNDIALS

Let's compare the solar time, indicated by our sundials, to the clock time.

On your sundial, mark 4 different clock times where the shadow crosses the scale. Each clock time should be at least 15 minutes later than the previous.

To compare your measurements to what we'd expect under ideal conditions, let's do some calculations. Complete the table below.

Clock time	Minutes after noon, m	Distance from noon to shadow (cm)	Theoretical distance from noon to shadow*	Error (cm)

*To determine the theoretical distance from noon to shadow, make sure your calculator is set to interpret angles in degrees. This is the default setting on all our calculators. The display will show “D” or “DEG.” Then determine:

m4

Where m is the number of minutes after noon that corresponds to the clock time, and “tan” is the tangent function, which you’ll learn more about in eighth grade.

What could explain the difference between our recorded measurements and the theoretical values?

How could we adjust our sundial so that readings on our sundial were closer to clock time?

Appendix O: Arts Standards

Science and Engineering Practices

Asking questions and defining problems

A practice of science is to ask and refine questions that lead to descriptions and explanations of how the natural and designed world(s) works and which can be empirically tested.

Developing and using models

A practice of both science and engineering is to use and construct models as helpful tools for representing ideas and explanations. These tools include diagrams, drawings, physical replicas, mathematical representations, analogies, and computer simulations.

Planning and carrying out investigations

Scientists and engineers plan and carry out investigations in the field or laboratory, working collaboratively as well as individually. Their investigations are systematic and require clarifying what counts as data and identifying variables or parameters.

Analyzing and interpreting data

Scientific investigations produce data that must be analyzed in order to derive meaning. Because data patterns and trends are not always obvious, scientists use a range of tools—including tabulation, graphical interpretation, visualization, and statistical analysis—to identify the significant features and patterns in the data. Scientists identify sources of error in the investigations and calculate the degree of certainty in the results.

Using mathematics and computational thinking

In both science and engineering, mathematics and computation are fundamental tools for representing physical variables and their relationships. They are used for a range of tasks such as constructing simulations; solving equations exactly or approximately; and recognizing, expressing, and applying quantitative relationships.

Constructing explanations and designing solutions

The end-products of science are explanations and the end-products of engineering are solutions. The goal of science is the construction of theories that provide explanatory accounts of the world. A theory becomes accepted when it has multiple lines of empirical evidence and greater explanatory power of phenomena than previous theories.

Engaging in argument from evidence

Argumentation is the process by which evidence-based conclusions and solutions are reached. In science and engineering, reasoning and argument based on evidence are essential to identifying the best explanation for a natural phenomenon or the best solution to a design problem.

Obtaining, evaluating, and communicating information

Scientists and engineers must be able to communicate clearly and persuasively the ideas and methods they generate. Critiquing and communicating ideas individually and in groups is a critical professional activity.

Crosscutting Concepts

Patterns

Observed patterns in nature guide organization and classification and prompt questions about relationships and causes underlying them.

Cause and effect

Events have causes, sometimes simple, sometimes multifaceted. Deciphering causal relationships, and the mechanisms by which they are mediated, is a major activity of science and engineering.

Scale, proportion, and quantity

In considering phenomena, it is critical to recognize what is relevant at different size, time, and energy scales, and to recognize proportional relationships between different quantities as scales change.

Systems and system models

A system is an organized group of related objects or components; models can be used for understanding and predicting the behavior of systems.

Energy and matter

Tracking energy and matter flows, into, out of, and within systems helps one understand their system's behavior.

Structure and function

The way an object is shaped or structured determines many of its properties and functions.

Stability and change

For both designed and natural systems, conditions that affect stability and factors that control rates of change are critical elements to consider and understand.

Disciplinary Core Ideas

Life Science	Earth & Space Science	Physical Science
From molecules to organisms: Structures and processes LS1.A: Structure and function LS1.B: Growth and development of organisms LS1.C: Organization for matter & flow in organisms LS1.D: Information processing	**Earth's place in the universe** ESS1.A: The universe and its stars ESS1.B: Earth and the solar system ESS1.C: The history of planet Earth	**Matter and its interactions** PS1.A: Structure and properties of matter PS1.B: Chemical reactions PS1.C: Nuclear processes
Ecosystems: Interactions, energy, and dynamics LS2.A: Interdependent relationships in ecosystems LS2.B: Cycles of matter and energy transfer in ecosystems LS2.C: Ecosystem dynamics, functioning, and resilience LS2.D: Social interactions and group behavior	**Earth's systems** ESS2.A: Earth materials and systems ESS2.B: Plate tectonics and large-scale system interactions ESS2.C: The roles of water in Earth's surface processes ESS2.D: Weather and climate ESS2.E: Biogeology	**Motion and stability: Forces and interactions** PS2.A: Forces and motion PS2.B: Types of interactions PS2.C: Stability and instability in physical systems
Heredity: Inheritance and variation of traits LS3.A: Inheritance of traits LS3.B: Variation of traits	**Earth and human activity** ESS3.A: Natural resources ESS3.B: Natural hazards ESS3.C: Human impacts on Earth systems ESS3.D: Global climate change	**Energy** PS3.A: Definitions of energy PS3.B: Conservation of energy & energy transfer PS3.C: Relationship between energy & forces PS3.D: Energy in chemical processes & everyday life
Biological evolution: Unity and diversity LS4.A: Evidence of common ancestry and diversity LS4.B: Natural selection LS4.C: Adaptation LS4.D: Biodiversity and humans		**Waves and their applications in technologies for information transfer** PS4.A: Wave properties PS4.B: Electromagnetic radiation PS4.C: Information technologies & instrumentation

Engineering, Technology, and the Application of Science

ETS1.A: Defining and delimiting engineering problems
ETS1.B: Developing possible solutions
ETS1.C: Optimizing the design solution

Appendix Q: Motion Graph Story

Motion Graph Story

Your task is to write a story about your motion and then create a labeled graph to show that motion. You will also create a colorful illustration that depicts your story. For this task you must:

1. Write a story which includes several changes in motion. For example, using a time-distance graph: I left my house to take the dog for a ***walk.*** The dog ***stopped*** to do his business and I cleaned it up. Our ***walk*** resumed. Suddenly, the dog saw a squirrel and ***chased*** after it. We ***stopped*** for several moments, and then ***returned home***. Each highlighted phrase would have a specific designation on the graph.
2. Create a graph that shows the different motions in your story. You do not need to have intervals on your graph.
3. Create a colorful illustration of your story.

Challenge:

You can include specific speeds for your motions. If you do this, your graph will need to have numeric intervals. If you say you are traveling 5 meters per minute, then your graph will need to increase by 1 minute for every 5 meters of distance. If you choose to do this option, please set up a consultation with Professor Crawford or Young to be sure you are doing it correctly.

Fun Option:

You can ask a classmate to partner with you to create this project. If you choose this option, we must receive an email from both parties. You are responsible for setting up your own meetings on Google meet or Zoom.

Appendix R: Hall of Planet Earth Museum Exhibition Design

In this lesson, students are designing murals for the Hall of Planet Earth at the Natural History Museum in New York City. At the exhibit they will learn about the different rock formations and how they came to be. Once they have done their research, they will create murals that will educate and give insight to the public about where the rock came from and its prior state before it arrived at the museum. Students will experience what it is like to be both a scientist and an artist to complete this task.

Museum Exhibition Design

You are an artist and have just been hired at the American Museum of Natural History in New York City. The curators have decided they would like to add a several murals (a painting or other work of art executed directly on a wall) to the David S. and Ruth L. Gottesman Hall of Planet Earth. Here is some info about the collection:

> *"The David S. and Ruth L Gottesman Hall of Planet Earth, located in the Rose Center for Earth and Space, displays an outstanding collection of geological specimens from around the world to show how our planet works....*
>
> *The hall features 168 rock specimens, many of which can be touched, and 11 full-scale models of classic outcrops chosen to illustrate an important aspect of Earth's dynamic story. Interactive exhibits let visitors explore geologic time, peer into the planet's depths, and understand the scientific methods used to stud it. The regularly updated Earth Bulletin highlights important topics in Earth Science.*
>
> *Featured specimens come from nearly all corners of the globe and include purse sulfur formed in an Indonesian volcano, a fossil stromatolite from the Sahara Desert in Mauritania, and a rock from New York City's Central Park. The hall's oldest specimen is a zircon crystal from Australia that formed about 4.3 billion years ago, only 200 million years after Earth itself. "*

Your task is to visit the exhibit (either online or in person) and pick 2 rock formations. The museum has done an excellent job of displaying the various types of rocks (Igneous, Sedimentary, and Metamorphic) however, they would now like to give visitors insight into how the rocks came to be.

Mural Part 1:

- Depiction prior to the rock formation
- Items to consider: were the rocks part of a bigger landscape (i.e. volcano)? Were there organisms living in the rocks? Were these rocks underwater?

Mural Part 2:

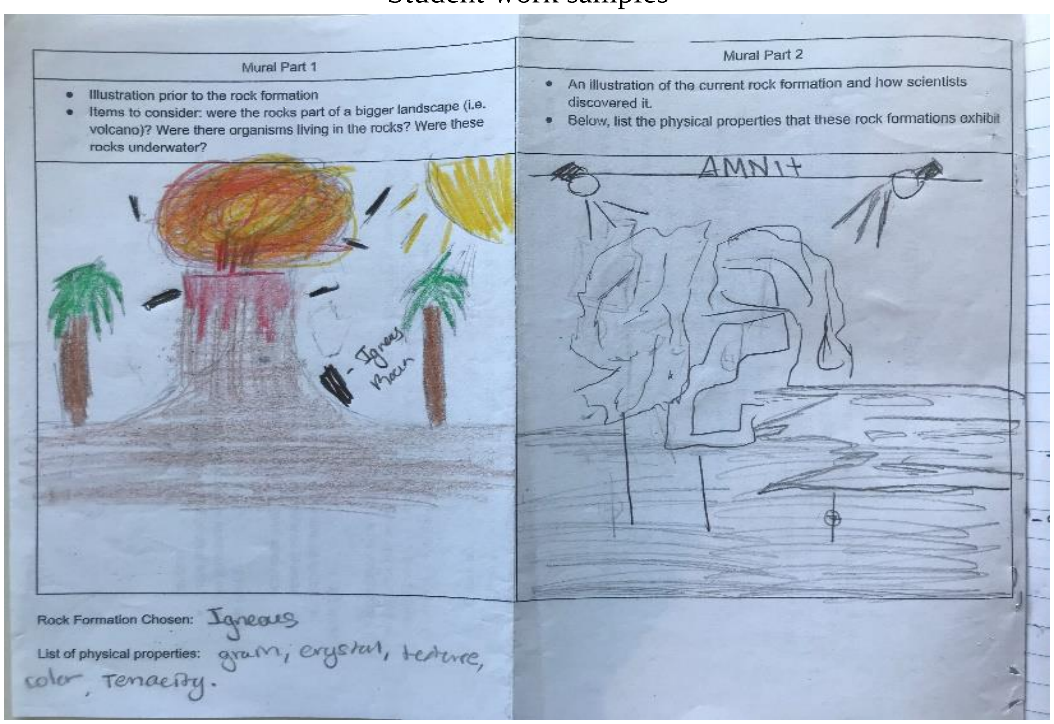
- An illustration of the current rock formation and how scientists discovered it.
- At the bottom, list the physical properties that the rock formation you have chosen contains

Mural Part 1	Mural Part 2
• Illustration prior to the rock formation • Items to consider: were the rocks part of a bigger landscape (i.e. volcano)? Were there organisms living in the rocks? Were these rocks underwater?	• An illustration of the current rock formation and how scientists discovered it. • Below, list the physical properties that these rock formations exhibit

Rock Formation Chosen:

List of physical properties:

Student work samples



Appendix S: Isabella's Lesson Plan for St. John the Divine Cathedral Field Trip

St. John The Divine	
Title of the Lesson **Learning About Medieval Architecture at St. John The Divine**	[redacted]

Lesson designed for Grade 6	**Time Required for Lesson: 4 lesson**
Lesson Description **Goal(s): Students will learn about ST. John The Divine and Medieval Architecture.** Students will learn about Romanesque and Gothic architecture And create an architectonical model.	
Big Idea(s) of this Lesson **Students will understand that:** **Objectives: Difference characteristics between Medieval Romanesque style and Gothic.** **created detail from observation. Combining different shapes patterns and lines.** Students will learn about medieval architecture and related acoustic. **Medieval Romanesque and Gothic revival cathedrals.** can be found in the eighteen and nineteen centuries, some architects choose to use Romanesque or Gothic style when created construction as mansions and cathedrals. If students have seen any of these they can relate to or share their experiences. Some students may have been previously exposed to optical illusions. With the use of the pencils, students will use variations of line to create sketches and complete a Romanesque façade drawing. They will learn about space and sound. When finished, students should have created a model on paper. First class- Drawing Introduction-Motivation and Key Question-5-8 min. **Today, we are going to sketch some detail from a medieval cathedral.** **Demo- 3 minutes** **Work period-20 min.** **Clean up-4 min.**	**Essential Question(s) of this Lesson:** **Students will answer:** Motivation and Key Questions: 5-8 minutes DOK1: Have you ever saw this cathedral before? Have you ever seen any medieval cathedral? DOK2: How do you think the architects created this construction? DOK 3: What are some characteristics of the Romanesque cathedrals? Introduce Vocabulary words: Romanesque/Gothic DOK 3: What are some things that you notice in the Romanesque cathedrals? What about Gothic cathedrals? DOK 4: What would you draw to obtain an image that resemble a Romanesque façade detail?

<table>
<tr><th colspan="2">Indicators of Student Learning</th></tr>
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CONTENT – Students will know:

Students will learn about Romanesque and Gothic architecture.
Students will create a model of medieval cathedral.
Key Vocabulary:
Gothic and Romanesque details and patterns
Romanesque:
Barrel & groin vaults
Gothic Architecture:
Rounded arch
Acoustic and relationship with the environment
Blueprint- Parallel line: (adjective) Lines that are side by side having the same distance continuously between them.
Perpendicular: (adjective) Two straight lines that intersect to create a 90° angle.
Geometric shape: a shape that has clear edges; created by humans generally.
Organic shapes: shapes found in nature; have a flowing a curving appearance
</td>
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SWBAT
Understand the elements of composition and principal of design

Understand the different hatching

SKILLS – Students will be able to create elevations drawing:

Create a drawing that demonstrates:

• sustained observation inspired by student curiosity

• the ability to create the illusion of space through perspective and scale of objects and figures

• the use of a range of values to describe volume and form

• purposeful use of drawing pencils, charcoal, pastels, and pen and ink to create varied line quality and visual textures

• ability to use drawing tools in inventive ways such as stippling, hatching, cross-hatching, and blending

• organization of composition, using foreground, middle ground, and background

• Create a design model of a cathedral that demonstrates:

• unity through the use of foamboard, drawing, color, line, shape, and texture

• attention to balance, emphasis, and proportion

• the integration of color, line, and shape to express a clear message

• inventive integration of text where applicable

• Create a model
</td>
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Visual Arts Blueprint Strands Addressed				
Artmaking • Explore art materials and techniques • Develop skills and techniques • Extend knowledge of art media • Deepen imaginative capacities • Engage in close observation and sustained investigation • Develop individual and global perspectives on art • Utilize Elements of Art and Principles of Design in artwork • Develop a personal style • Cultivate awareness of the power of art to understand medieval art	**Visual Arts Literacy** • Hone observational skills in discussing works of art • Develop visual arts vocabulary to describe art tools and techniques • Utilize Elements of Art and Principles of Design in speaking and writing about artwork • Read and write about art to gain knowledge and to reinforce literacy skills • Interpret artwork by providing evidence to support assertions • Reflect on the process of making art	**Making Connections** • Recognize the societal, cultural, and historical significance of art • Connect visual arts to other disciplines • Apply skills and knowledge learned in visual arts to interpreting the world	**Community and Cultural Resources** • Access primary sources in the community, borough, and city to extend learning beyond the classroom (including cultural institutions, colleges, and universities) • Use visual arts research resources in libraries and museums • Mine school community, families, and local business as resources to enhance arts education	**Careers and Lifelong Learning** • Learn about careers in and related to visual arts • Recognize and articulate personal and professional goals • Develop a career plan • Gain an appreciation of art as a source of enjoyment and lifelong learning

Common Core Learning Standards Addressed

Students will: **Standard 1:** Creating, performing, and participating in the Art.
Standard 3: Responding to and analyzing Works of art.
BLUEPRINT: GRADE 6
1. Create a print that demonstrates: printmaking techniques, unity of composition

__ demonstrate independence.
__ build strong content knowledge.
__ respond to the varying degrees of audience, task, purpose, and discipline.
__ comprehend as well as critique
__ value evidence.
__ come to understand other perspectives and cultures.

Learning Experiences

STYLE	ROMANESQUE	VS.	GOTHIC
EMPHASIS	HORIZONTAL		VERTICAL
ELEVATION	MODEST HEIGHT		SOARING
LAYOUT	MULTIPLE UNITS		UNIFIED, UMBROKEN SPACE
MAIN TRAIT	ROUNDED ARCH		POINTED ARCH
SUPPORT SYSTEM	PIERS, WALLS		EXTERIOR BUTTRESSES
ENGINEERING	BARREL & GROIN VAULTS		RIBBED GROIN VAULTS
AMBIANCE	DARK, SOLEMN		AIRY, BRIGHT
EXTERIOR	SIMPLE, SEVERE		RICHLY DECORATED WITH SCUPLTURE

Culminating Class Activity

CAN YOU SKETCH HERE A LITTLE DETAIL FROM THE ROSE WINDOW (CIRCULAR WINDOW FILLED WITH STAINED GLASS)?

CAN YOU SKETCH A DETAIL FROM THE NAVE (PART OF CHURCH INTERIOR)

CAN YOU SKETCH GOTHIC ARCH?

CAN YOU SKETCH A DETAIL FROM THE VAULT (ARCHED CEILING)?

CAN YOU SKETCH A DETAIL FROM THE RIBBED VAULT?

Suggested Resources for this Lesson

Appendix T: Sample Menu Instruction Sheet

Every Friday, students were given a menu of activities from which they could choose. These activities revolved around the theme of the COVID-19 Pandemic and how students were processing what was occurring. Below is a sample instruction sheet that students received each week. They had the entire day to complete several of the activities.

COVID Chronicles Week 2
4/24/2020

Friday
Instructions:
For this week you will complete 2-3 the activities assigned for today. Today's tasks are listed in the table below. Each activity is categorized by task, and you will see an approximate time span next to each task. You will submit any deliverables to this discussion question by attaching them directly to this assignment. Your responses can be in the form of a google document, a photo, image file, or video file.

Friday's Tasks
DRAW for 15-30min Prompt:
Create a birds-eye view of an ideal hospital
WRITE for 15min creatively **Prompt:**
How have your eating habits changed? Talk about your eating habits were before the virus and the virus
READ

Non-Fiction: Read the following article:: https://www.iwh.on.ca/what-researchers-mean-by/epidemiology and then answer the following questions:
What is epidemiology?

- What are some of the tasks that epidemiologists carry out?
- What issues or obstacles do you think epidemiologists experience as they are working? How are they issues?
- Do you agree with that author that epidemiology is important for public health? Why or why not?

For the fiction portion, please read one of the poems from the attached selection. Then, respond to or complete one of the following prompts:

- Write your own poem or story inspired by, or in imitation of, this poem.
- Are there connections between this poem and your life right now? If so, you could write (or draw, or both) about them.
- Create an illustration, drawing, audio or video clip inspired by this poem. Write two sentences to explain how your art was inspired by the poem.
- Have someone else read this poem and discuss it with them. You could have the discussion by typing in Hangouts and copy and paste the chat to submit it. Or, you could have the discussion out loud, and record the audio.